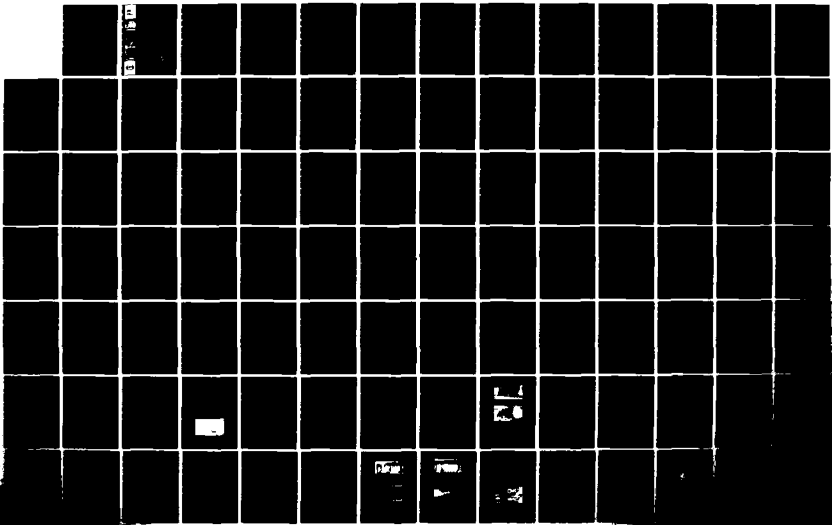
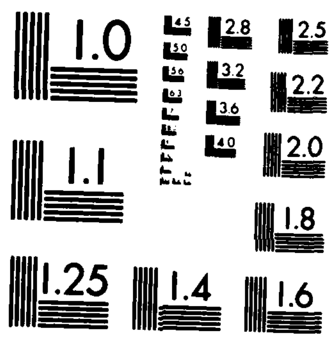
AD-A142 827 PROCEEDINGS OF THE ANNUAL MEETING AQUATIC PLANT CONTROL 1/3
RESEARCH PROGRAM (..(U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS ENVIR.. JUN 84
UNCLASSIFIED WES/MP/A-84-4 F/G 6/6 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

US Army Corps of Engineers

AD-A142 827

(12)

AQUATIC PLANT CONTROL RESEARCH PROGRAM

MISCELLANEOUS PAPER A-84-4

PROCEEDINGS, 18TH ANNUAL MEETING, AQUATIC PLANT CONTROL RESEARCH PROGRAM

14-17 NOVEMBER 1983

RALEIGH, NORTH CAROLINA

June 1984

Final Report

Prepared for Office, Chief of Engineers, U.S. Army
Washington, D.C. 20314

Published by Environmental Laboratory
U.S. Army Engineer Waterways Experiment Station
P.O. Box 631, Vicksburg, Miss. 39180

JUL 1 3 1984

COMPONENT PART NOTICE

THIS PAPER IS A COMPONENT PART OF THE FOLLOWING COMPILATION REPORT: **A**

(TITLE): Proceedings of the Annual Meeting, Aquatic Plant Control Research Program (18th) Held at Raleigh, North Carolina on 14-17 November 1983

(SOURCE): Army Engineer Waterways Experiment Station, Vicksburg, MS. Environmental Lab.

TO ORDER THE COMPLETE COMPILATION REPORT USE AD-A142 827.

THE COMPONENT PART IS PROVIDED HERE TO ALLOW USERS ACCESS TO INDIVIDUALLY AUTHORED SECTIONS OF PROCEEDINGS, ANNALS, SYMPOSIA, ETC. HOWEVER, THE COMPONENT SHOULD BE CONSIDERED WITHIN THE CONTEXT OF THE OVERALL COMPILATION REPORT AND NOT AS A STAND-ALONE TECHNICAL REPORT.

THE FOLLOWING COMPONENT PART NUMBERS COMPRISE THE COMPILATION REPORT:

COMPONENT PART NOTICE (CON'T)

AD#:	TITLE:
P003 606	Chemical Control Technology Development: The Use of Controlled Release Fluridone Fibers for Control of Hydrilla in Flowing Water
P003 607	Chemical Control Technology Development: Determination of the Fluridone Concentration/Contact Time Relationship for the Control of Myriophyllum spicatum and Hydrilla verticillata
P003 608	Chemical Control Technology Development: Herbicide/ Adjuvant Evaluation in Flowing Water
P003 609	Chemical Control Technology Development: Pilot-Scale Production of Fibers for the Controlled Release of Fluridone
P003 610	Chemical Control Technology Development: Preliminary Field Evaluation of Controlled-Release Fluridone Fibers
P003 611	Ecology of Aquatic Species: Effects of Sediment Compositio Composition
P003 612	Ecology of Aquatic Plant Species: Effects of Water Chemistry on Aquatic Plant Species: Preliminary Studies on Myriophyllum spicatum
P003 613	The "Carolina" Session: Growth, Reproduction, and Biomass of Hydrilla in North Carolina
P003 614	The "Carolina" Session: Hydrilla Management in North Carolina
P003 615	The "Carolina" Session: Status of Alligatorweed Control in North Carolina
P003 616	The "Carolina" Session: A Major Utilities Program to Manage Aquatic Weeds
P003 617	The "Carolina" Session: Aquatic Macrophyte Distribution in the Santee Cooper Lakes - A Study Approach
P003 618	The "Carolina" Session: Aquatic Plant Problems and Management in South Carolina

A-1

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Miscellaneous Paper A-84-4	2. GOVT ACCESSION NO. AD-A142827	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PROCEEDINGS, 18TH ANNUAL MEETING, AQUATIC PLANT CONTROL RESEARCH PROGRAM, 14-17 NOVEMBER 1983, RALEIGH, NORTH CAROLINA		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Engineer Waterways Experiment Station Environmental Laboratory P.O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Aquatic Plant Control Research Program
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U.S. Army Washington, D.C. 20314		12. REPORT DATE June 1984 13. NUMBER OF PAGES 204
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aquatic plant control — Congresses
Research planning — Congresses

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The 18th Annual Meeting of the U.S. Army Corps of Engineers Aquatic Plant Control Research Program was held in Raleigh, North Carolina, on 14-17 November 1983, to review current research activities and to afford an opportunity for presentation of operational needs. Papers presented at the meeting are included in this report. These papers include reports of research being conducted in the areas of biological, chemical, and mechanical control methods, and the ecology of problem plants. In addition, papers are included that present the operational problems in various Corps of Engineer Districts. A specific section on aquatic plant problems in the North and South Carolina is included.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

The 18th Annual Meeting of the U.S. Army Corps of Engineers Aquatic Plant Control Program was held in Raleigh, North Carolina, on 14-17 November 1983. The meeting is required by Engineer Regulation (ER) 1130-2-412 paragraph 4c and was organized by personnel of the Aquatic Plant Control Research Program (APCRP), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

The organizational activities were carried out and presentations by WES personnel were prepared under the general supervision of Dr. John Harrison, Chief, EL. Mr. J. Lewis Decell was Program Manager, APCRP. Mr. W. N. Rushing, APCRP, was responsible for planning and chairing the meeting. Mr. E. Carl Brown was Technical Monitor for the Office, Chief of Engineers, U.S. Army.

COL Tilford C. Creel, CE, was Commander and Director of the WES at the time of this meeting and during the preparation of the proceedings report. Mr. F. R. Brown was Technical Director.

CONTENTS

AGENDA

18th Annual Meeting
U.S. Army Corps of Engineers
AQUATIC PLANT CONTROL RESEARCH PROGRAM

Raleigh, North Carolina
14-17 November 1983

MONDAY, 14 NOVEMBER 1983

10:00 a.m. -5:30 p.m.	Registration—Explanade—3rd Floor
6:30 p.m.	Reception—Explanade—3rd Floor

TUESDAY, 15 NOVEMBER 1983
General Session, Oak Forest Ballroom
Section A

8:00 a.m.	Registration Continues
8:30 a.m.	Call to Order and Announcements —W. N. Rushing, Waterways Experiment Station (WES), Vicksburg, Miss.
8:45 a.m.	Welcome to the Wilmington District —COL Wayne Hanson, Commander, USAE District, Wilmington, N.C.
9:00 a.m.	Keynote —Hon. Earl G. Droessler, Assistant Secretary for Natural Resources, North Carolina Department of Natural Resources and Community Development (NC DNR&CD), Raleigh, N.C.
9:30 a.m.	General Comments —J. L. Decell, Manager, Aquatic Plant Control Research Program, WES
9:45 a.m.	BREAK
10:00 a.m.	USAE Division/District Presentations—Aquatic Plant Problems—Operations Activities
12:00 noon	LUNCH
1:30 p.m.	Mechanical Control Technology Development—An Overview —H. W. West, WES
1:45 p.m.	New Algorithms for the HARVEST Model and Demonstrations Using a Microcomputer —T. D. Hutto, WES
2:00 p.m.	Conceptual Development for Control Method Effectiveness and Field Tests Planned for FY 84 —B. M. Sabol, WES
2:15 p.m.	Discussion
2:30 p.m.	Biological Control Technology Development; An Overview Including Wrap-Up of Large Scale Operations Management Test with Insects and Pathogens in Louisiana —D. R. Sanders, WES
2:50 p.m.	BREAK

3:10 p.m. Biological Control Activities in Texas and California
—A. F. Cofrancesco, Jr., WES

3:25 p.m. Microbiological Control of Hydrilla with Lytic Enzymes
—J. C. Pennington, WES

3:40 p.m. Microbiological Control of Eurasian Watermilfoil
—H. B. Gunner, University of Massachusetts, Amherst

3:55 p.m. Overseas Surveys of Biocontol Agents for Hydrilla
—J. K. Balciunas, USDA, Ft. Lauderdale, Fla.

4:10 p.m. Impacts on Waterhyacinths of the Two Species of Weevils (Neochetina) and their Population Dynamics
—T. D. Center, USDA, Ft. Lauderdale

4:25 p.m. Ten Year Update of the Status of Alligatorweed in the Southeast
—A. F. Cofrancesco, Jr., WES

4:40 p.m. Discussion

4:55 p.m. Adjourn for the day

WEDNESDAY, 16 NOVEMBER 1983
General Session - Oak Forest Ballroom
Section A

8:30 a.m. Chemical Control Technology Development - An Overview
—H. E. Westerdahl, WES

8:45 a.m. Herbicide Evaluation Program
—T. K. Van, USDA, Ft. Lauderdale

9:00 a.m. Threshold Herbicide Concentration and the Relation Between Concentration and Exposure Time
—J. F. Hall, WES

9:15 a.m. Herbicide/Adjuvants for Use in Flowing Water
—K. D. Getsinger, WES

9:30 a.m. BREAK

9:50 a.m. Scale-up Requirements for Controlled Release Poly GMA - 2,4-D
—F. W. Harris, University of Akron, Ohio

10:05 a.m. Development and Production of Controlled Release Fluridone Fibers
—R. L. Dunn, Southern Research Institute, Birmingham, Ala.

10:20 a.m. Preliminary Field Evaluation of Controlled Release Fluridone Fibers
—H. E. Westerdahl, WES

10:35 a.m. Discussion

10:50 a.m. Ecology of Aquatic Plant Species - Major Effects of Sediment Composition
—J. W. Barko, WES

11:05 a.m. Effects of Water Chemistry on Aquatic Plant Species
—R. M. Smart, WES

11:20 a.m. Discussion

11:45 a.m. LUNCH

1:30 p.m. The "Carolina" Session
—R. Jackson, USAE District, Wilmington

1:40 p.m. Development of a State Aquatic Weeds Program
—J. N. Morris, Director, Office of Water Resources (NC DNR&CD), Raleigh*

1:55 p.m. Growth Characteristics of Hydrilla in the Carolinas
—G. J. Davis, Dept. of Biology, East Carolina Univ., Greenville, N.C.

---

* Presentation not submitted for inclusion in proceedings.

2:10 p.m.	Development of Strategies to Manage Hydrilla —G. Pesacreta, Sea Grant Program, North Carolina State Univ. (NCSU), Raleigh —K. Wilson, North Carolina Dept. of Agriculture* —K. Langeland, Crop Science Dept., NCSU
2:40 p.m.	BREAK
3:00 p.m.	A Major Electric Utilities Program to Manage Aquatic Weeds —D. Schiller, Carolina Power and Light Co., Raleigh
3:15 p.m.	Submersed Aquatic Plants in Lakes Marion and Moultrie, South Carolina —R. Harvey, Project Manager, Santee-Cooper River Basin Water Quality Study, South Carolina Dept. of Health and Environmental Control, Columbia, S.C.
3:30 p.m.	Aquatic Plant Management in South Carolina —Danny Johnson, South Carolina Water Resources Commission
4:00 p.m.	Final Wrap-up
4:15 p.m.	Adjourn 18th Annual Meeting

THURSDAY, 17 NOVEMBER 1983
Live Oak Room

8:00 a.m.-11:00 a.m.	FY 85 Civil Works R&D Program Review, Directorate of Research and Development, OCE (Corps of Engineers Representatives Only)

* Presentation not submitted for inclusion in proceedings.

ATTENDEES

18th Annual Meeting
U.S. Army Corps of Engineers
AQUATIC PLANT CONTROL RESEARCH PROGRAM

Raleigh, North Carolina
14-17 November 1983

Rick Bailey
Wake County Soil and Water
Conservation District
Raleigh, NC 27611

Joe Balciunas
USDA Aquatic Plant Management
Laboratory, 3205 SW College Ave.
Fort Lauderdale, FL 33314

John Barko
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

Wayne Batten
Wake County Agricultural
Extension Service
Raleigh, NC 27611

Orrin Beckwith
USAE Division, North Pacific
PO Box 2847
Portland, OR 97208

Les E. Bitting, Sr.
Old Plantation Water Control
District, PO Box 15405
Plantation, FL 33325

Robert P. Blakeley
Old Plantation Water Control
District, 7049 NW 4 St.
Plantation, FL 33317

Richard K. Blush, Jr.
USAE Division, Lower Mississippi
Valley, PO Box 80
Vicksburg, MS 39180

Edwin L. Boren
USAE Division, Lower Mississippi
Valley, PO Box 80
Vicksburg, MS 39180

E. Carl Brown
Office, Chief of Engineers
DAEN-CWO-R
Washington, DC 20314

Earl R. Burns
Tennessee Valley Authority
E&D Building
Muscle Shoals, AL 35660

Ted Center
USDA Aquatic Plant Management
Laboratory, 3205 SW College Ave.
Fort Lauderdale, FL 33314

James Choromokos
Office, Chief of Engineers
DAEN-RDZ-A
Washington, DC 20314

Al Cofrancesco
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

Graham J. Davis
East Carolina University
Biology Department
Greenville, NC 27834

J. Lewis Decell
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

David J. DeMint
North Carolina State University
Raleigh, NC 27607

C. R. Dillon
Clemson University
Biology Department
Clemson, SC 29631

Michael Dodd
J. H. Kerr Reservoir
Boydton, VA 23917

Earl Droessler
North Carolina Department of
Natural Resources and Community
Development, PO Box 27687
Raleigh, NC 27661

Richard L. Dunn
Southern Research Institute
2900 9th Avenue, So.
Birmingham, AL 35205

Mike Dupes
USAE District, Jacksonville
PO Box 4970
Jacksonville, FL 32232

Pamela C. Ellis
Orange Water and Sewer Authority
PO Box 366
Cauboro, NC 27510

Michael J. Eubanks
USAE District, Mobile
PO Box 2288
Mobile, AL 36628

Frank Fernandez
Applied Biochemists
730 Rockborough Dr.
Stone Mountain, GA 30083

Johnnie Frizzell
Pennwalt Corporation
Rt. 1, Box 471
Hope Hall, AL 36043

John Gallagher
Union Carbide
PO Box 12014
Research Triangle Park, NC 27709

Nancy Gallagher
Union Carbide
PO Box 12014
Research Triangle Park, NC 27709

Edwin Gavin
North Carolina Department of
Natural Resources and Community
Development, PO Box 27687
Raleigh, NC 27611

Kurt D. Getsinger
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

Sally Gladstone
North Carolina Department of
Agriculture, Biocontrol Lab
Raleigh, NC 27611

Mark H. Glaze
US Environmental Protection
Agency
Washington, DC 20460

Donald L. Grant
Lilly Research Labs
3035 Directors Row #408
Memphis, TN 38131

Haim B. Gunner
Department of Environmental
Sciences
University of Massachusetts
Amherst, MA 01003

Jerry F. Hall
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

COL Wayne Hanson
USAE District, Wilmington
PO Box 1890
Wilmington, NC 28402

Steve M. Harlan
East Carolina University
Biology Department
Greenville, NC 27834

Frank W. Harris
University of Akron
Department of Polymer Chemistry
Akron, OH 44325

Keith Harris
USAE District, Wilmington
Falls Lake, PO Box 61068
Raleigh, NC 27661

John Harrison
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

Tom Hart
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

Richard Harvey
South Carolina Department of
Health and Environmental Control
PO Box 72
State Park, SC 29142

Ronald G. Hodson
North Carolina State University
105 1911 Bldg.
Raleigh, NC 27502

Andy Hogshead
Westvāco Polychemicals
PO Box 70848
Charleston Heights, SC 29405

Tom Howard
North Carolina State Parks
Raleigh, NC 27611

Allan J. Hruska
North Carolina Department of Agriculture, Biocontrol Lab
Raleigh, NC 27611

Tommy Hutto
USAE Waterways Experiment Station, PO Box 631
Vicksburg, MS 39180

Bernard Ingram
USAE District, Wilmington
PO Box 1890
Wilmington, NC 28402

Richard Jackson
USAE District, Wilmington
PO Box 1890
Wilmington, NC 28402

Danny Johnson
South Carolina Water Resources Commission, PO Box 4440
Columbia, SC 29240

Joyce Johnson
USAE District, Galveston
PO Box 1229
Galveston, TX 77553

Mike Jones
Chevron Chemical Co.
1728 Montreal Circle
Tucker, GA 30084

Scott Jorgensen
American Lake and Canal
439 NW 14th Pl. #B
Crystal River, FL 32629

Joe Joyce
Center for Aquatic Weeds
University of Florida
1922 NW 71st Street
Gainesville, FL 32606

Joe Kight
USAE District, Mobile
Lake Seminole Resource Managers Office, PO Box 96
Chattahoochee, FL 32324

Eddie Knight
USAE District, Jacksonville
(Palatka Area Office)
PO Box 1317
Palatka, FL 32077

Wayne Koerner
USAE District, St. Paul
1135 USPO & Customs House
St. Paul, MN 55101

Porter Lambert
St. Johns River Water Management District
Palatka, FL 32007

Ken Langeland
North Carolina State University
Weed Science Center
3123 Ligon St.
Raleigh, NC 27607

Coleman Long
USAE District, Wilmington
PO Box 1890
Wilmington, NC 28402

Bill Maier
Florida Natural Resources
Center for Aquatic Weeds
1922 NW 71st Street
Gainesville, FL 32606

Philip Mancusi-Ungaro
South Carolina Department of Health and Environmental Control
PO Box 72
State Park, SC 29142

Loren M. Mason
USAE District, Tulsa
PO Box 61
Tulsa, OK 74121

Jim McGehee
USAE District, Jacksonville
PO Box 4970
Jacksonville, FL 32232

Terry McNabb
American Lake and Canal
1818C Arnold Industrial Place
Concord, CA 94520

Tom McNabb
American Lake and Canel
1818C Arnold Industrial Place
Concord, CA 94520

Jim Mead
North Carolina Department of Natural Resources and Community Development
Office of Water Resources
Box 27687
Raleigh, NC 27611

Will Miller
Bluewater Harvester, Inc.
10014 North Dale Mabry
Tampa, FL 33618

Diane Moody
North Carolina Department of
Natural Resources
Division of Environmental
Management
PO Box 27687
Raleigh, NC 27611

Myles Moore
Chemically Sensitive
Raleigh, NC 27611

John Morris
North Carolina Department of
Natural Resources and Community
Development, PO Box 27687
Raleigh, NC 27611

Ed Moyer
USAE District, Fort Worth
4140 Sanguinet
Fort Worth, TX 70102

Christine Nalepa
North Carolina Department of
Agriculture
Raleigh, NC 27611

Larry Nall
Florida Department of Natural
Resources
3900 Commonwealth Blvd.
Tallahassee, FL 32303

Judy Pennington
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

George Pesacreta
North Carolina State University
Zoology Department
Raleigh, NC 27607

Larry Petrovich
Wake County Soil and Water
Conservation District
Raleigh, NC 27611

Jesse A. Pfeiffer, Jr.
Office, Chief of Engineers
DAEN-RDC
Washington, DC 20314

Clayton Phillippy
Florida Game and Fresh Water
Fish Commission
620 S. Meridian St.
Tallahassee, FL 32301

Carroll Pierce
North Carolina Department of
Natural Resources and Community
Development
Raleigh, NC 27611

James B. Porter
PO Box 253
Franklin, NC 28734

John Pringle
Bureau of Reclamation
Denver Federal Center
PO Box 25007
Denver, CO 80225

Gerald Purvis
USAE Division, South Atlantic
510 Title Bldg., 30 Pryor St., SW
Atlanta, GA 30303

Robert Rawson
USAE District, Seattle
PO Box C-3755
Seattle, WA 98124

Danny Riley
Florida Department of Natural
Resources
3900 Commonwealth Blvd.
Tallahassee, FL 32303

John Rodgers
Department of Biological Sciences
North Texas State University
Denton, TX 76203

William N. Rushing
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

Bruce Sabol
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

Dana R. Sanders, Sr.
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

David H. Schiller
Carolina Power & Light Co.
Rt. 1, Box 327
New Hill, NC 27562

Tom Schulte
USAE District, Savannah
PO Box 889
Savannah, GA 31402

Howard Singletary
North Carolina Department of
Agriculture, PO Box 27647
Raleigh, NC 27611

Michael Smart
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

William B. Smith
North Carolina Wildlife Resources
Commission, Rt. 1, Box 416
Battleboro, NC 27809

Keith Steele
USAE District, Sacramento
650 Capitol Mall
Sacramento, CA 95814

Jim Stewart
Water Resources Research Institute
124 Riddick Bldg.
North Carolina State University
Raleigh, NC 27650

Karen Stone
Carolina Power & Light Company
Raleigh, NC 27611

John Sutherland
North Carolina Department of
Natural Resources and Community
Development
Raleigh, NC 27611

David P. Tarver
Elanco
2416 McWest St.
Tallahassee, FL 32303

Fred R. Tarver
North Carolina State University
Zoology Department
Raleigh, NC 27607

Thai K. Van
USDA Aquatic Plant Management
Laboratory
3205 SW College Ave.
Fort Lauderdale, FL 33314

H. Wade West
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

Howard Westerdahl
USAE Waterways Experiment
Station, PO Box 631
Vicksburg, MS 39180

Chuck Wilson
USAE District, Wilmington
PO Box 1890
Wilmington, NC 28402

John Wilson
North Carolina State University
Department of Horticulture
Raleigh, NC 27607

Karen G. Wilson
North Carolina Department of
Agriculture, PO Box 27647
Raleigh, NC 27611

John Wray
North Carolina Department of
Natural Resources and Community
Development, Box 27687
Raleigh, NC 27611

Carolyn Zarnekee
USAE District, Portland
PO Box 2946
Portland, OR 97208

Debbie Zeleznick
North Carolina State University
Raleigh, NC 27607

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
acre-feet	1233.489	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
gallons per acre	0.00093	cubic decimetres per square metre
gallons (U.S. liquid)	3.785412	cubic decimetres
horsepower (550 foot-pounds per second)	745.6999	watts
inches	25.4	millimetres
miles (U.S. statute)	1.609347	kilometres
pounds (mass) per acre	0.000112	kilograms per square metre
pounds (mass) per gallon	0.12	kilograms per cubic decimetre
square miles	2.589998	square kilometres
tons (mass) per acre	0.22	kilograms per square metre
tons (2000 lb mass)	907.1847	kilograms

18th Annual Meeting
U.S. Army Corps of Engineers

AQUATIC PLANT CONTROL RESEARCH PROGRAM

INTRODUCTION

As part of the Corps of Engineers (CE) Aquatic Plant Control Research Program (APCRP) it is required that a meeting be held each year to provide for professional presentation of current research projects and review current operations activities and problems. Subsequent to these presentations, the Civil Works Research and Development Program Review is held. This program review is attended by representatives of the Civil Works and Research Development Directorates of the Office of the Chief of Engineers; the Program Manager, APCRP; and representatives of the operations elements of various Division and District Engineer Offices.

The overall objective of this annual meeting is to thoroughly review Corps aquatic plant control needs and establish priorities for future research, such that identified needs are satisfied in a timely manner.

The technical findings of each research effort conducted under the APCRP are reported to the Manager, APCRP, U.S. Army Engineer Waterways Experiment Station (WES), each year in the form of quarterly progress reports and a final technical report. Each technical report is given wide distribution as a means of transferring technology to the technical community. Technology transfer to the field operations elements is effected through the conduct of demonstration projects in various District Office problem areas and through publication of Instruction Reports (IR), Engineering Circulars (EC), and Engineering Manuals (EM). Periodically, results are presented through publication of an APCRP Information Exchange Bulletin which is distributed to both the field units and the general community. Public-oriented brochures, movies, and speaking engagements are used to keep the general public informed.

The printed proceedings of the annual meetings and program reviews are intended to provide Corps management with an annual summary to ensure that the research is being focused on the current operational needs on a nationwide scale.

The contents of this report include the presentations of the 18th Annual Meeting held in Raleigh, North Carolina, 14-17 November 1983.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

Lower Mississippi Valley Division, New Orleans District

by
Edwin L. Boren*

New Orleans District's Aquatic Plant Control Program serves the State of Louisiana. Besides Corps of Engineers involvement, the State of Louisiana and several parishes (counties) have crews which spray many acres of unwanted aquatics each year.

The aquatic growth control operations at the New Orleans District (NOD) consist of the Removal of Aquatic Growth (Operations and Maintenance, General funds) and the Aquatic Plant Control Program (Construction General funds). The section has 4 office and 23 field personnel. Control of floating and submerged aquatics was accomplished during FY 83. This paper gives the status of the program during FY 83.

The Army Quarterboat Tambour was salvaged and all personnel reassigned to shore crew units during late FY 81 and early FY 82. This change resulted in 5 shore crew units being established at new duty stations. Presently, we have 11 two-man crews stationed at 8 duty stations. Overall, we have increased our control capabilities from 44,528 acres** in FY 82 to 53,576 acres in FY 83. The herbicide 2,4-D was used during 95 percent of our operations and diquat, aquathol K, cutrine plus, and rodeo were used during the other 5 percent.

Control operations were aimed mainly at waterhyacinth, but alligatorweed, pennywort, water paspalum, water lettuce, and hydrilla were also sprayed.

A contract for aerial spraying resulted in 4,831 acres (included in above figure) being controlled during August and September 1983. Many waterways between Bayou Gauche, Louisiana, and Morgan City, Louisiana, were sprayed for control of waterhyacinth during these 160 hr of operations.

Improvements to both office and field operations were made during FY 83. Office personnel modified the ADP Computer printouts to reflect different herbicides being utilized and to more accurately report spray operations by State of Louisiana and Corps of Engineers crews. Field personnel, on an experimental basis, worked 10-hr workdays, 4 days a week, which resulted in a 6-percent increase in spraying productivity. This action will be used again next year from April through October.

Four air boats were purchased in early FY 83 which also assisted in increasing field productivity. Radios were installed in all trucks to improve communications.

---

* U.S. Army Engineer Division, Lower Mississippi Valley, Vicksburg, Mississippi.

** A table of factors for converting U.S. customary units of measurement to metric (SI) is presented on page xii.

Water samples were collected by Corps personnel and analyzed by the University of Southwestern Louisiana (contract) for 2,4-D residue. Samples were collected at various intervals of time after spraying occurred to correlate time to residue of herbicide. Results have shown that after approximately 10 days, traces of the herbicide remained.

Construction General funds were used under the cooperative program to fund the Louisiana Department of Wildlife and Fisheries (contract) for work-in-kind under the cost-sharing program. An audit was conducted and $220,000 was paid to the State for these services. The State sprayed 48,447 acres with these monies. Construction General funds were used by Corps crews to control 17,953 acres, and Operations and Maintenance General funds paid for control of 30,792 acres by Corps crews (figure excludes aerial spraying).

Monthly helicopter flights for inspection and reconnaissance were initiated during FY 83 to assist in accomplishing this work on a timely basis.

The Aquatic Growth Control Section at the District attended the Louisiana Pesticide Applicators Association annual meeting in November 1983 for State pesticide applicators certification. All Corps employees were recertified at that time.

During FY 82 the Large-Scale Operations Maintenance Test (LSOMT) on waterhyacinth in Louisiana, which was conducted by the U.S. Army Engineer Waterways Experiment Station (WES) and funded by NOD, was concluded. Biological agents were released and several reports by WES on this study were prepared and released.

The Aquatic Growth Control Section has been busy with an ongoing A-76 contract feasibility study which was initiated in July 1982. This study will determine if the NOD operations stay in-house or are awarded to outside contractors. This study was partially completed in June 1983 and started again on 6 September 1983. The Management Study, Performance Work Statement, and Quality Assurance Surveillance Plan are being revised.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

Aquatic Plant Control Operations Support Center

by
James T. McGehee*

The Aquatic Plant Control Operations Support Center (APCOSC) was formally established in FY 81. The Center is located within the National Resource Management Section, Construction-Operations Division, of the Jacksonville District.

CENTER RESPONSIBILITIES

The policies, functions, and procedures for the use of Center services are set forth in Engineer Regulation 1130-2-412. The regulation describes the relationship between the APCOSC; the Office, Chief of Engineers (OCE); and the U.S. Army Engineer Waterways Experiment Station (WES) and establishes the following functions of the Center:

- Provide technical guidance to Corps Districts in planning phases of aquatic plant control programs.
- Provide technical guidance to Corps Districts in the operational phases of aquatic plant control programs.
- Provide technical expertise and/or operational personnel and/or equipment to respond to localized short-term critical situations created by excessive growths of aquatic plants.
- Provide assistance to OCE for the training and certification of Corps application personnel.
- Upon request, assist WES in field application and evaluation of newly developed control techniques or procedures.
- Provide assistance to OCE in the development of a comprehensive Corps-wide aquatic plant control program.

FISCAL YEAR 1983 ACTIVITIES

Table 1 provides a listing of the services performed by the Center and the types of users to which these services were provided during FY 83. A total of 125 requests for assistance were received and responded to by the APCOSC. This represents a decrease of 36 requests over the FY 81 effort. Since established, the Center has responded to a total of 367 requests.

During FY 83, Corps Districts accounted for 32 or 26 percent of the total services provided. The next most frequent user was state and local governments with 26 or 21 percent of the services. On a cumulative basis, 67 or 54 percent of the requests

* U.S. Army Engineer District, Jacksonville; Jacksonville, Florida.

Table 1
Aquatic Plant Control Operation Support Center
Fiscal Year 1983
Support Assistance Through 31 September 1983

Type Assistance	Corps OCE	Corps WES	Corps Div.	Corps Dist.	Other Federal	Other Country	State Local	Industry	Private	Total
Planning	5	2	3	11	0	0	9	9	3	41
Operations	2	10	1	20	15	0	15	12	0	75
Research	0	0	0	1	1	0	2	1	1	9
Training	0	0	0	0	0	0	0	0	0	0
Totals	7	15	4	32	16	0	26	21	4	125

were from non-Corps organizations. Twenty-one came from private industry or 6 percent of the total. The most frequently requested service was operational assistance. There were 75 operational requests or 60 percent of the total.

PLANNING

There were 41 planning services performed during the year. The services ran from simple explanations of the aquatic plant control planning process for Districts new to the program to detailed assistance in the formulation of planning documents. Significant activities included a continuation of previous assistance to Sacramento and Wilmington Districts in the planning required to start their programs.

OPERATIONS

Operationally oriented services accounted for the largest portion of the work for the year. The Center collected 60,000 alligatorweed flea beetles and shipped them to 13 separate organizations in 7 states. The beetles are not overwintering in large numbers in the northern range of alligatorweed. Users have reported faster and better control of the plants by reintroduction of the insects from south Florida at the very beginning of the growing season. The alligatorweed thrips has exhibited the ability to overwinter better than the flea beetle in northern Florida. The thrips appear to stress the plants earlier in the season than the flea beetle and attack terrestrial or rooted alligatorweed that the flea beetles usually do not attack. It is believed that the combination of the two insects will do a better job of alligatorweed control. In 1983 the Center collected 1000 thrips for WES to release in Texas to help in the biological control of this plant. Additional shipments of thrips to other areas in the southeast are planned for 1984.

Many of the issues concerning aquatic plant control are highly technical and very specific to the field. Those new to the field may find it very difficult and time-consuming to find answers or solutions to seemingly simple problems. The Center through its broad base of experience in the field has been able to quickly provide answers to these questions and workable solutions to the problems. The types of plant and equipment used for aquatic plant control are not the usual for Corps contracts. Establishing rental rates and estimating rental periods are therefore

unusual to most Corps Districts. A procedure has been established by the Center to compute rental rates for this equipment and we have a broad data base for estimating time requirements for particular jobs. Units of payment and technical provisions for aquatic plant control contracts may likewise be difficult for the uninitiated. The Center has provided guidance to WES and Corps Districts in the preparation of these contracts. The Center was host to several State legislators and State agency personnel from South Carolina in an overview of hydrilla problems and alternative corrective measures available. The administrative workings of the Aquatic Plant Control Program were also discussed at length for the benefit of the State personnel new to the program. The remainder of the operational services consisted of providing information or evaluations on the potential use of specific chemical, biological, or mechanical control methods and Aquatic Plant Control Program administrative procedures.

RESEARCH

Research services consisted of providing background information to researchers on current or past operational procedures or reviewing reports and proposed procedures from an operational standpoint. Assistance was provided to OCE during the year on seven occasions. The services included review and/or recommendations on general operational situations in other District programs, and operational review of reports. The Center has proposed and is cooperating with OCE in the development of a standardized cooperative agreement between the Corps and local governmental agencies to be used for the Aquatic Plant Control Program instead of contracts. This would eliminate many of the difficulties experienced by Districts in beginning a program and in administration of an ongoing program.

STATUS OF THE APCOSC

The Center's expenditure for FY 82 was $26,000. These funds covered personnel salaries for time expended for minor services and general maintenance of the Center functions. All expenses for travel and significant commitment of manpower for services were paid for by the using Corps elements.

Based on the number and types of requests received during FY 83, and the satisfactory fulfillment of the requested services, the APCOSC is continuing to perform the function for which it was established. The number of requests for assistance declined from last year by 22 percent. We do not believe that this is a trend. The Center is service oriented and it is expected that the numbers and degree of assistance will fluctuate from year to year. The inevitable spread of cold-tolerant aquatic plants like hydrilla and Eurasian watermilfoil to new water bodies over the Nation should increase the assistance requirements as new programs emerge to address the problem. Continued assistance for those Districts now in the planning stage is likewise expected as they move to an operational program.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

South Atlantic Division, Jacksonville District

by
Michael Dupes*

STATE OF FLORIDA

In cooperation with the Florida Department of Natural Resources, the Jacksonville District conducts aquatic plant control under two authorizations. One is the Removal of Aquatic Growths Project (RAGP) authorized by the River and Harbor Act of 1899. The other is the Aquatic Plant Control Program (APCP) authorized by Public Law 89-298 dated 1965. The RAGP is funded 100 percent by the Corps of Engineers and is the original operation and maintenance program for the control of aquatic vegetation in Federal navigation projects. The APCP is a cooperative program for the control of aquatic vegetation in other public navigable water bodies not included in the RAGP. This program is funded 70 percent by the Corps and 30 percent by the State or local governments.

The majority of actual control operations are handled under contract with the Florida Department of Natural Resources, which in turn has subcontracted the work to five water management districts and seven counties. Jacksonville District spray crews are responsible for control operations in the St. Johns River between Jacksonville and Lake Washington.

Maintenance control of waterhyacinth was continued during FY 1983 with no significant problems occurring throughout the year. The total area of waterhyacinths treated during the year was 18,852 acres and the area of waterhyacinth/water lettuce mix was 15,208 acres.

Fiscal year 1983 has been a good year and a bad year for managing hydrilla in the state. Several new infestations have been located throughout the state and some lakes that had small infestations now have larger ones that will require extensive treatments during FY 1984. However, acceptable control of hydrilla has been obtained using Sonar in several lakes in Polk and Orange Counties, and for the first time in several years Orange Lake is virtually free of hydrilla. The results of the Sonar treatment in those lakes look very promising for future management of hydrilla in lakes. It now appears that we might have a tool that will achieve maintenance control of hydrilla. The total acreage of hydrilla treated state-wide during FY 1983 was 9283 acres.

Waterhyacinth and hydrilla are the major problem species in the state. However, in some areas minor plant species can grow profusely and restrict navigation. These

* U.S. Army Engineer District, Jacksonville; Jacksonville, Florida.

plants are not of widespread concern, but, on a local scale, can cause sufficient problems to warrant control. Total acreage of minor plants treated during the year was 1880 acres.

PUERTO RICO

Aquatic plant control in Puerto Rico is also within the Jacksonville District's jurisdiction and is performed under PL 89-298 in cooperation with the Puerto Rico Department of Natural Resources (DNR). Control operations are directed primarily towards waterhyacinths which have significantly impacted most of the canals, reservoirs, and rivers on the island.

The program became operational in 1982 after being in the planning stage since 1974 pending the resolution of several environmental issues. The Environmental Quality Board (EQB) of Puerto Rico is concerned about potential effects 2,4-D may have on the environment, and whether or not water quality standards will be met. In order to determine the effects 2,4-D will have on the environment, the EQB agreed to let the DNR treat a portion of Rio De La Plata to monitor 2,4-D residues and various environmental parameters. This was phase one of a two-phase study. The second phase will take place in an upland lake.

Phase one started on 14 July 1982 with Corps and DNR personnel treating approximately one half an acre of waterhyacinths in Rio De La Plata near Toa Alta. Samples of water, hydrosoil, and fish were collected for a month following treatment and analyzed for 2,4-D residue. The results of the monitoring indicated that the treatment had a negligible effect on the environment and did not violate the water quality standards established by the EQB. However, some of the samples taken after treatment showed elevated phenol and nutrient levels. In view of the monitoring results, DNR requested a permit from the EQB to treat several canals and streams that have severe waterhyacinth problems and also to treat Dos Bocas Lake. Dos Bocas Lake is the proposed site of phase two of the monitoring study which was scheduled to take place during the summer of 1983. In May of 1983 the EQB approved the following nine sites for treatment using 2,4-D:

- Canal Campanero (Toa Baja)
- Canal Villa Calma (Toa Baja)
- Rio Cocal (Toa Baja)
- Cano Cabo Caribe (Vega Alta)
- Cano La Malaria (Cantano)
- Laguna Cucharillas (Cantano)
- Canal Blasina (Carolina)
- Quebrada Las Margaritas (San Juan)
- Rio La Plata, by the bridge in Dorado

These sites were approved with the requirement that phenol and nutrient levels be monitored.

Still concerned about potentially adverse effects from the use of 2,4-D, the EQB did not approve Lake Dos Bocas for treatment nor did they approve the herbicide for general aquatic use in Puerto Rico. Since Dos Bocas was not approved, phase two of the monitoring study was delayed.

During FY 1983 DNR was able to obtain maintenance control in Cano La Malaria. They expect to have the other approved sites under maintenance control by the end of FY 1984. Phenol and nutrient monitoring will take place in conjunction with spray operations.

The initial emphasis of the Aquatic Plant Control Program in Puerto Rico is herbicidal control. However, as biological control agents are approved for release, they will be incorporated into the program. The required research to obtain approval for release of the waterhyacinth weevil has been completed. As soon as official approval is granted by the Puerto Rican Government, the insect will be released. Additional studies are planned for obtaining approval for the release of the waterhyacinth moth.

SUMMARY

In summary, maintenance control of waterhyacinths continued in Florida during FY 1983. New infestations of hydrilla were found throughout the state; however, the results of Sonar treatments in some lakes show promise for managing hydrilla. The Aquatic Plant Control Program in Puerto Rico is getting off to a slow start due to environmental issues. Nine water bodies were approved for treatment during the year by the EQB and are expected to be under maintenance control by the end of FY 1984.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

North Pacific Division, Seattle District

by
Robert M. Rawson*

We have just completed the fourth year of Eurasian watermilfoil control in the State of Washington. The work is done under a Cooperative Agreement between the Seattle District and the Washington State Department of Ecology.

We have four main areas of concern in the state: the Lake Washington drainage in the Seattle area, the Okanogan area in north-central Washington; the Pend Oreille River in eastern Washington; and the Columbia River reservoirs. No Corps reservoirs are infested at this time.

The milfoil population in the Lake Washington drainage is fairly stable now and fluctuates mainly due to weather conditions. Mechanical harvesting and fiberglass bottom screens are the treatments of choice in this area because of local opposition to chemical control.

In the Okanogan area, the main treatment sites are located in lake Osoyoos. Two thirds of the lake are in Canada, and the lower third is in the United States. The Canadian side has heavy milfoil growth which they treat with mechanical harvesters. The U. S. portion has only scattered weed beds which are kept under control by annual treatments of granular 2,4-D.

Only operational testing with herbicides and adjuvants is being done in the Pend Oreille River. This area is of concern because of the possibility of upstream spread into Lake Pend Oreille in Idaho. We have initiated a public information program in the area to reduce as much as possible the chance of a boater's transporting fragments around Albeni Falls Dam and into the lake. Since we have no authorized Aquatic Plant Control Program in Idaho, this effort is funded out of project operation and maintenance funds.

The most important water area in the state is the Columbia River. We tried for several years to bottle up the milfoil in the Okanogan system, but found that it wasn't possible. Milfoil became established at the mouth of the Okanogan River in 1980 and has been moving downstream in the Columbia ever since. Presently, it is as far down as Wanapum Dam, approximately halfway to the Pacific Ocean.

As part of our cooperative program, the Department of Ecology has studied test treatments of 2,4-D with inverting oils or polymers. The results have been disappointing. I believe the State will propose no further treatment in the Columbia River until technology advances in the field of treatment in flowing water systems. This problem is one of Seattle District's main concerns, the almost total lack of

* U.S. Army Engineer District, Seattle; Seattle, Washington.

treatment options in flowing waters. We strongly support WES's continued research in this field until a longer term biological control can be developed.

Another problem that has been with us from the start of our program has been the lack of a strong local funding base. The Department of Ecology is the local sponsor for the program, but has limited funding available. They have had to pass a majority of the local share down to individual local governments. They have found a progressively larger proportion of their administrative effort being taken up in negotiating local contracts and trying to find funding sources.

Because of this problem, Governor Spellman, 2 months ago, signed an Executive Order establishing an interagency task force to take another look at the entire problem and make recommendations to the State legislature.

So far, the task force has succeeded in getting the other State agencies who are affected by milfoil involved in looking at the problem and alternative treatment strategies. Hopefully, the task force effort will result in a more stable funding base and a more comprehensive strategy for milfoil control state-wide.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

South Pacific Division, Sacramento District

by
Keith Steele*

LOCATION AND DESCRIPTION

The Sacramento-San Joaquin Delta is located in the Central Valley of California about 50 miles northeast of San Francisco. The Delta consisting of about 420 square miles has about 60 major tracts and islands separated by 700 miles of waterways. The area is developed primarily for agricultural purposes. However, many of the meandering sloughs and waterways have aesthetic qualities which make the Delta attractive to various boating and other recreational uses. Since the Delta is located near large population centers such as San Francisco, Sacramento, and Stockton, there are many people using this valuable resource. Also, since the Delta has warm summers and mild winters, boating and other water-oriented recreation continues throughout the year. Water-dependent visitor days in the Delta are estimated to be about 6 million per year.

PROBLEMS

Waterhyacinth problems in the Delta are primarily connected with water-related recreation activities and water supply systems for irrigation and manufacturing and industry needs. Marinas, boat harbors, and other small craft facilities are numerous. Over 150 commercially operated marinas provide facilities for a wide variety of boats. All the recreation activities such as boating, fishing, swimming, and waterskiing are adversely affected by the hyacinth. The plants create safety hazards to boaters and obstruct water diversion and pumping facilities. Together the Bureau of Reclamation and the State of California deliver over 5.5 million acre-feet of water annually to central and southern California for agricultural, municipal, and industrial purposes. The Bureau has expended 100's of 1,000's of dollars the past few years removing the plants at the Delta-Mendota Canal pumping facility.

CORPS ACTIVITIES

The Sacramento District became actively involved in the Delta hyacinth problem in the fall of 1981 when the California Department of Boating and Waterways (DBW) requested our assistance. Recommendations provided by the U.S. Army Engineer Waterways Experiment Station for a control program were given to the

* U.S. Army Engineer District, Sacramento; Sacramento, California.

DBW in May 1982. These recommendations included mechanical, biological, and chemical methods of control. With funds provided by the State of California, the DBW has initiated a control program. The mechanical portion has been limited to the placement of floating booms to limit the plants' movement and spreading. Nursery areas for the weevil *Neochetina bruchi* have been established as part of the biological portion of the program. It will take time, probably several years, to see how effective this method will be.

The chemical part of the program has been implemented successfully the past summer season. The herbicides 2,4-D and Diquat were used. The 2,4-D is more effective than Diquat and is considered the preferred herbicide from the standpoint of effectiveness and economic cost; however, a court injunction in Contra Costa County has prohibited the use of 2,4-D in that county. The Delta is divided basically into three counties with the problem areas primarily in the two counties of Contra Costa and San Joaquin. Sacramento-San Joaquin Counties have not prohibited the use of 2,4-D; therefore, the program implemented by the DBW has been very successful in San Joaquin County, except for areas bordering Contra Costa County. In these areas the plants are moving across the county line with the tidal currents and westerly winds.

The opposition to the use of herbicides to control waterhyacinth comes from a group of individuals in Contra Costa County. Their concern is that their water supply will become contaminated. Even though the Federal, State, and county health and environmental protection agencies have testified that the program has adequate safeguards to protect the public interest, this group continues action to prevent the use of herbicides. When the court prohibited the use of 2,4-D in Contra Costa County, the DBW used Diquat. Now the Contra Costa County group is seeking to stop the use of all herbicides on waterhyacinth. They believe the plants should be removed by mechanical methods. A citizen volunteer group attempted to remove the plants with small boats and hand tools. Their efforts resulted in a large number of people learning that the problem is much too great to control with this approach. It appears the court action taken against the use of 2,4-D was because of a lack of legal environmental documentation requirements rather than scientific evidence of potential adverse impacts.

The Sacramento District is presently preparing a State Design Memorandum and Environmental Assessment in order to request authorization for participation in the Federal Aquatic Plant Control Program. It appears that the main problem with implementing an aquatic plant control program is gaining acceptance by court actions and public opinion.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

Southwestern Division, Tulsa District

by
Loren M. Mason*

INTRODUCTION

Due to the documented diversity of aquatic plant infestations in Oklahoma ponds, lakes, and reservoirs over the past 10 years, the Tulsa District, in cooperation with the State of Oklahoma, formulated a State Design Memorandum for funding control programs under the Aquatic Plant Management Program, Public Law 89-298, dated 1965. To date, no work has been accomplished with the State under the management program, nor is any work anticipated within the next several years due to declining State general funds and lack of demonstrable impacts of aquatic plants upon the state's economy at the present time.

As to project operations aquatic plant problems, the District has two projects with infestations of Eurasian watermilfoil (*Myriophyllum spicatum*): Pat Mayse and Robert S. Kerr Lock and Dam and Reservoir. The infestation on Robert S. Kerr continues to remain stable and is considered to be insignificant compared to the previously large acreage which existed in 1978 and 1979. On the other hand, the infestation at Pat Mayse Lake has continued to expand, causing serious problems which have created conditions necessary for a control program.

After several years of extensive coordination with State and Federal agencies and cooperation of Mother Nature, the Tulsa District initiated its first aquatic plant control program on 14 June 1983 at Pat Mayse Lake, located in northeast Texas, approximately 8 miles north of Paris, Tex.

The problem species within Pat Mayse, a 6000-surface-acre lake is Eurasian watermilfoil which expanded from 50 acres in 1978 to 1000 acres in 1981 and 1982. High lake levels and turbid conditions caused by floodwaters in June, July, and August 1982 reduced the watermilfoil infestation level to approximately 500 acres by August 1982; however, the reduction was only temporary and by October 1983, the watermilfoil had expanded to approximately 600 acres. As a result of the previous infestation levels, conditions in 1983 again resulted in over 90 percent of the recreational shoreline being inaccessible and the seven swimming beaches and three of the projects' eight boat ramps became unusable.

COORDINATION AND TREATMENT

In order to ensure a treatment program in 1983, it was necessary to obtain an Emergency Exemption Permit from the Environmental Protection Agency as well

* U.S. Army Engineer District, Tulsa; Tulsa, Oklahoma.

as to obtain concurrence from the Texas State Department of Health, Texas Water Resources Board, Texas Parks and Wildlife Department, and the City of Paris prior to initiating treatment. Numerous planning meetings were conducted, and water quality data was collected by North Texas State University to predict advanced impacts of the control program upon the water supply for the City of Paris.

To minimize treatment impacts and maximize public benefits, the control program was limited in its scope by directing efforts toward opening the recreational shoreline, swimming beaches, and boat ramps. As a result, the total treatment acreage was reduced to 93 acres. To further minimize application impacts, within the 93 acres a granular formulation of dipotassium salt of endothall (Aquathol) was selected. Based upon the watermilfoil biomass, shoot density, and 6- to 10-ft water depths, the granular endothall was applied at a rate of 250 lb/acre to achieve the desired concentration level of 2.5 ppm.

The treatment sites were surveyed using a fathometer mounted to a Corps airboat and hand-held range finder to determine water depths and distances and surface acreage. The outer perimeters of the treatment areas were marked with clear 1-gal plastic jugs every 100 ft, secured to 1/4-in. nylon cord, and anchored to a brick. The outer limits of the shoreline perimeters were marked with 3-ft wooden stakes and red survey tape for easy visibility.

To ensure visitor notification, metal public notice warning signs were placed in all six treatment areas. A total of 50 signs were placed both on land and water. Each sign read, "This area has been treated with Aquathol - an aquatic herbicide. No swimming or fishing allowed. For information, please call (214) 732-3020."

The metal signs were bolted, utilizing two 3/8-in. bolts and nuts (top and bottom) to 7-ft U channel steel posts. The signs for the water were backed with plywood or old metal signs, utilizing four 1/2- by 8-in. bolts placed over the top of can buoys and tightened until secure. The buoys and posts were installed 5 days prior to treatment with the signs being mounted on the posts and buoys 3 days prior to treatment. The signs remained in place for 3 days after treatment to ensure adequate time to determine endothall levels prior to reopening the treated areas.

The day before treatment, operation and maintenance workers loaded and transported the 40-gal herbicide containers from the project storage compound to the various treatment sites in support of the applicating crews from the Texas Parks and Wildlife Department (TP&WD). On treatment day, 14 June 1983, total time required for application of the herbicide over the 93 acres, utilizing two TP&WD crews, was 8 hr.

During the application time, four project rangers conducted surveillance actions to ensure that the public complied with the no fishing and swimming restrictions established for the treatment areas. The rangers entered each area at least 2 hr in advance of treatment to ensure public awareness, and a Corps airboat was used to facilitate surveillance on the water. In addition, gate attendants of three of the six recreational areas began notifying the public 4 days prior to treatment.

WATER QUALITY MONITORING

In support of the 1983 treatment program, the District contracted with North Texas State University to collect pertinent data for evaluating the impacts of endothall upon water quality, as well as fish and bottom sediments.

One of the primary concerns of the study was to determine the biodegradation rate of endothall within the lake. To answer these questions, six sampling stations were established with one serving as a statistical control area. Sampling was initiated at the sites for the following parameters:

- Temperature
- Dissolved oxygen
- Endothall
- pH
- Turbidity
- Chlorophyll *a*

In addition to the above sampling, each site was sampled for sediment and fish. Frequency of sampling at all stations occurred 7 days before treatment, day of treatment, 7 days after treatment, and 30 days after treatment. Details of the sampling program are available in the following paper by Dr. John Rodgers.

CONCLUSIONS

Based upon results of the 1983 sampling work, there is sufficient data to verify that the endothall dissipated rapidly within the first 24 hr after treatment and that endothall was not detectable after 72 hr.

Results of the treatment are that a 100-percent kill of the Eurasian watermilfoil occurred in the treated area and that no detectable adverse impacts occurred in the treated or untreated areas. These results verify that endothall can be used effectively and safely for the control of Eurasian watermilfoil in water supply lakes such as Pat Mayse Lake.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the excellent cooperation and highly professional participation of the Texas Parks and Wildlife Department under supervision of Mr. Lou Guerra and the North Texas State University under supervision of Dr. John H. Rodgers, Jr., in the implementation of the 14 June 1983 treatment program.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

Pat Mayse Lake, Texas, Aquatic Plant Management Program: Water Quality Monitoring

by

John H. Rodgers, Jr.,* Kevin H. Reinert,* and Mark L. Hinman*

INTRODUCTION

A water quality monitoring program was conducted on Pat Mayse Lake during the summer of 1983 in conjunction with an aquatic weed management program. The purpose of this monitoring program was to collect pertinent water quality data to evaluate the impacts of applying a herbicide to this Texas reservoir. In addition, the monitoring would identify any violation of drinking water standards and any potential problem areas in relationship to future water resources activities.

Pat Mayse Lake (PML), a 5990-acre reservoir located in Lamar County, Texas, is operated by the Tulsa District as a water supply for the City of Paris, Texas, and for recreation, as wildlife habitat, and for flood control (Figure 1). Eurasian watermilfoil was probably first introduced to PML in 1976, and became apparent in June 1978 when approximately 74 acres of the lake were occupied by the plant. By November of the same year, milfoil was estimated to cover 351 acres. The severe winters of 1979 and 1980 reduced the milfoil infestation to less than 200 acres at the end of summer 1980. By the fall of 1981, over 1000 acres were infested, involving about 80 percent of the 67-mile shoreline. Following a period of heavy rains in the spring of 1982, the milfoil infestation covered about 474 acres by August (Figure 2) (Rodgers, Hinman, and Reinert 1982). This reduction in coverage was temporary and the plant has increased its distribution during the 1983 growing season.

Heavy milfoil infestation contributes various problems for PML. Visitation to the lake dropped during the period of September 1980 through August 1981 to 42 percent of the previous year.** Damage to boat motors has increased with increasing milfoil infestation. In the summer of 1980, a drowning occurred in a milfoil-infested area near Lamar Point.†

MATERIALS AND METHODS

Endothall (Aquathol Granular Aquatic Herbicide - Pennwalt Corporation) was used in this aquatic plant management program to treat six areas within Pat Mayse Lake which were infested with Eurasian watermilfoil; six sampling stations were established in these areas. A seventh sampling station was established at the City of Paris, Texas, water intake as a control site (Figure 1). Water, sediments, and fish

* Department of Biological Sciences and Institute of Applied Sciences, North Texas State University, Denton, Texas.

** Personal Communication, J. J. Harmon, District Engineer, Tulsa District, 25 January 1982.

† Personal Communication, Paul Gray, CE Project Manager, Pat Mayse Lake, 1982.

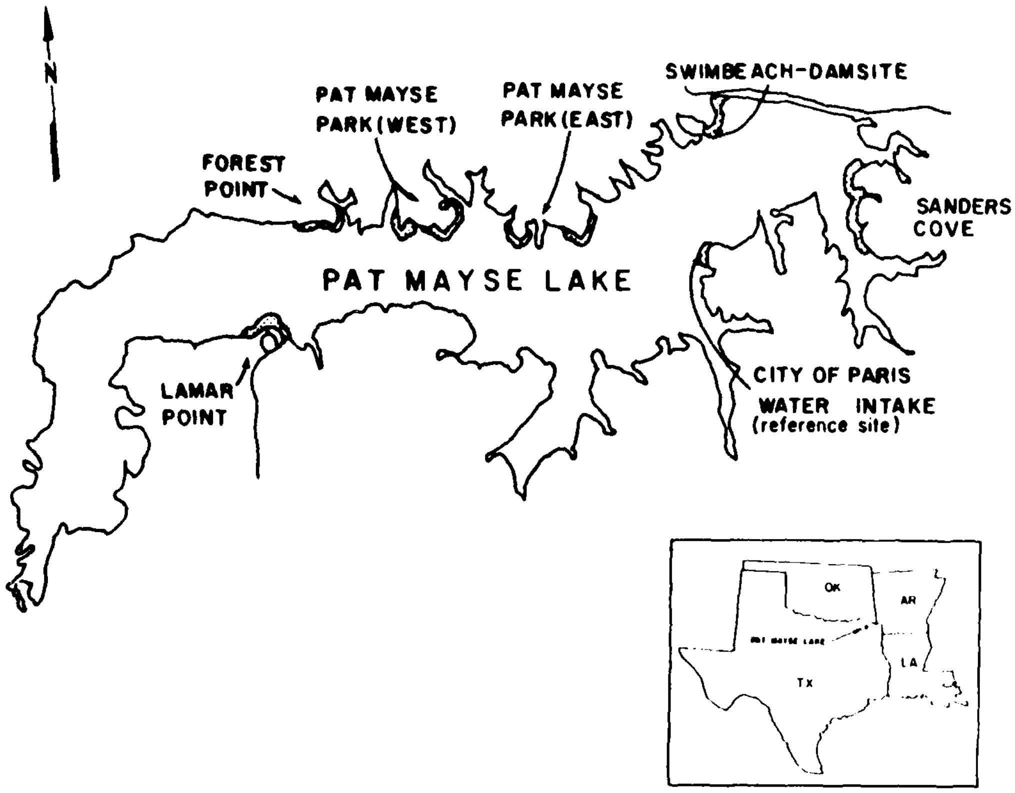


Figure 1. Location of Pat Mayse Lake and water quality monitoring stations

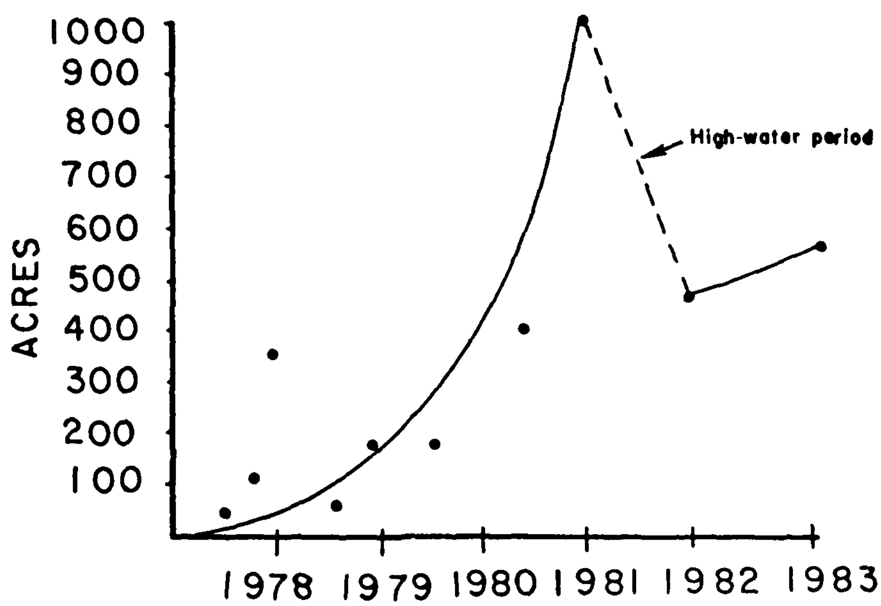


Figure 2. Eurasian watermilfoil invasion of Pat Mayse Lake

were collected and analyzed for endothall by gas chromatography (Carlson, Whitaker, and Landskor 1978; Sikka and Rice 1973). In addition, water samples were analyzed for temperature, dissolved oxygen, pH, turbidity, and chlorophyll *a*. The herbicide was applied on 14 June 1983 by crews from the Texas Department of Parks and Wildlife. Sampling occurred on the following dates: 7 June 1983 (7 days prior to treatment); 14 June 1983 (treatment day); 17, 21, and 24 June and 14 July 1983 (days 3, 7, 10, and 30 after treatment, respectively).

RESULTS AND DISCUSSION

Endothall was not detected in the vicinity of the City of Paris water intake and the drinking water standard for endothall was not exceeded. No endothall was detected in the water, sediments, or fish samples that were collected 30 days after herbicide treatment (Figures 3 and 4). None of the water quality parameters were significantly altered due to herbicide use (Figures 5-9). No impacts of nontarget aquatic organisms were detected. Endothall rapidly dissipated within 72 hr from the treatment areas. Both dispersion (dilution) and biodegradation probably contributed significantly to rapid transfer and degradation.

The rapid removal of endothall from Pat Mayse Lake water was expected (Simsiman, Daniels, and Chesters 1976). The lack of sorption and persistence of endothall in sediments was also predictable (Reinert and Rodgers, in press) as were the undetectable concentrations in fish tissue (Armstrong 1974; Chiou et al. 1977; Veith, Defoe, and Bergstedt 1979). This herbicide has several characteristics that made it especially advantageous, given the special water resource usages at PML.

The treatment program was apparently very successful and approximately 100-percent control of milfoil was obtained in the treatment areas with no adverse effects observed (Figure 10). The aquatic weed problem was alleviated and the lake was returned to normal usage capacity. There was an apparent increase in visitation to Pat Mayse Lake and usage of the treated sites. However, rapid regrowth and dispersal capabilities of milfoil (Grace and Wetzel 1978) may mean that regular monitoring and continued application of management techniques will be required. Initial reestablishment of milfoil in treated areas was observed approximately 2 months after treatment. The time required for the milfoil in the treated areas to achieve previous densities or biomass levels will have to be determined by continued monitoring.

CONCLUSIONS

The following conclusions are indicated:

Endothall was not detected in the vicinity of the City of Paris water intake. The drinking water standard for endothall was not exceeded in any of the samples.

No endothall was detected in the water, sediments, or fish samples that were collected 30 days after herbicide treatment of Pat Mayse Lake.

None of the water quality parameters were significantly altered due to herbicide use. No impacts on nontarget organisms were detected.

Endothall was rapidly dissipated from the treatment areas. Both dispersion (dilution) and biodegradation probably contributed significantly to rapid transfer and degradation.

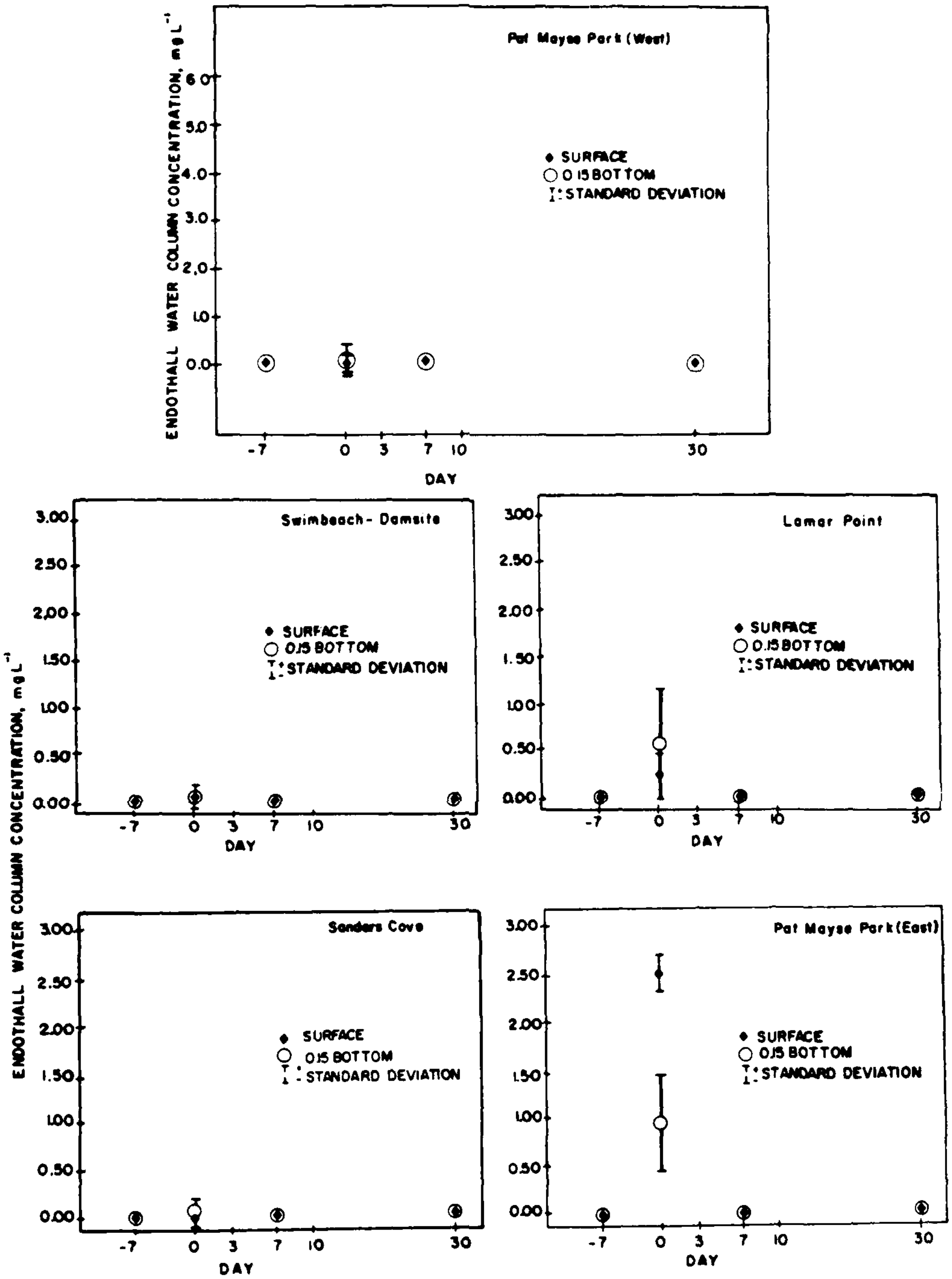


Figure 3. Water column concentrations of endothall at Lamar Point, Pat Mayse Park (east), Pat Mayse Park (west), the swimbeach-damsite, and Sanders Cove

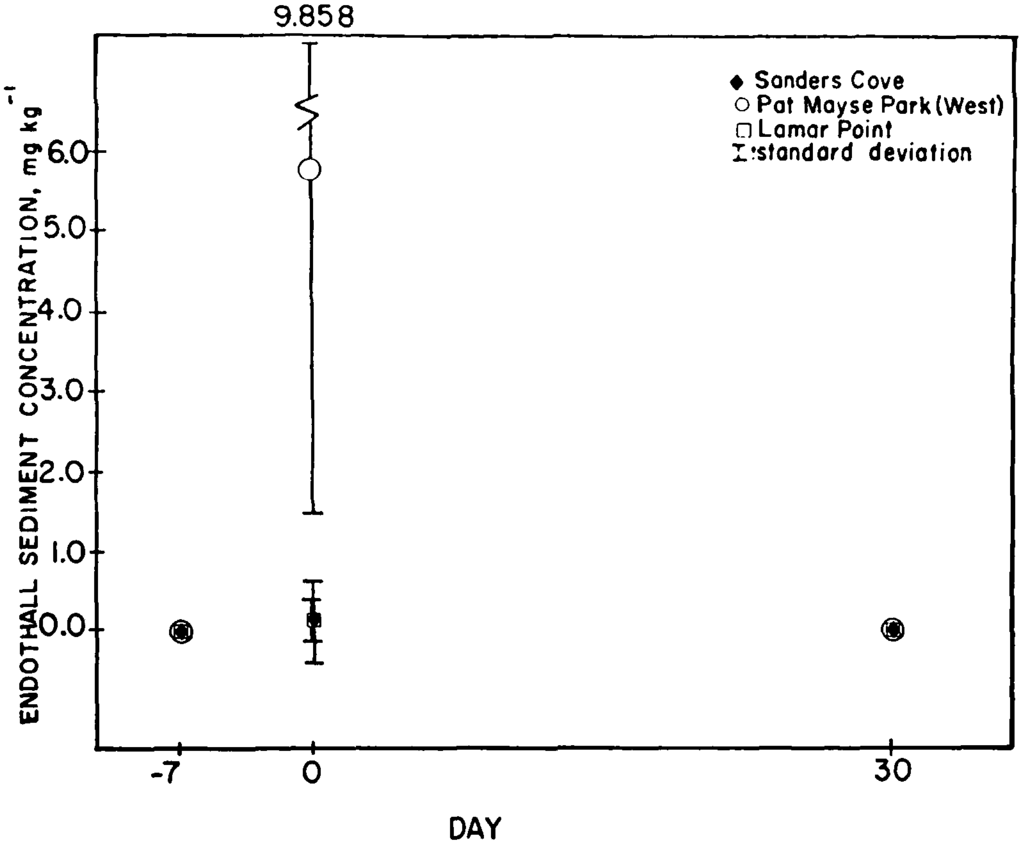


Figure 4. Endothall concentrations in sediments at sampling stations that contained detectable levels on the day of treatment (day 0)

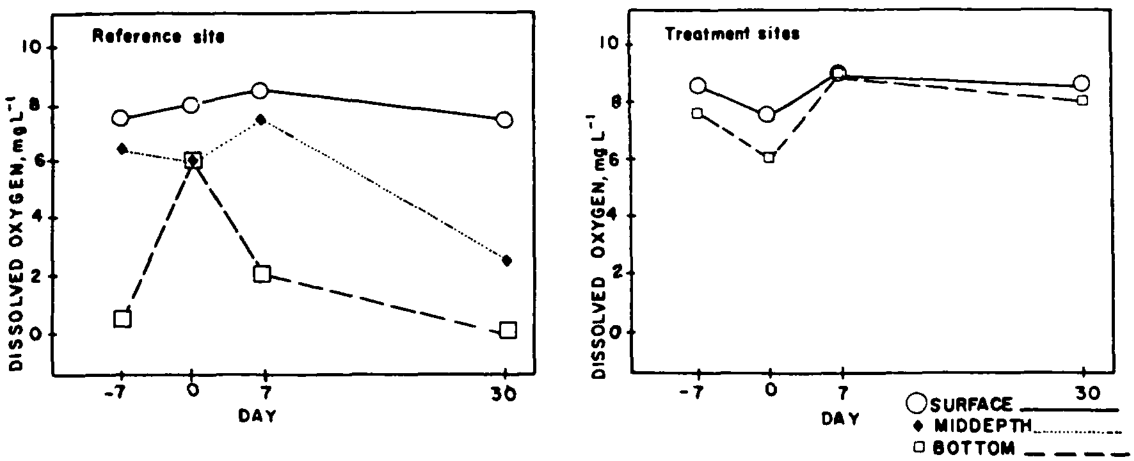


Figure 5. Dissolved oxygen concentrations at the treatment sites and the reference site (control)

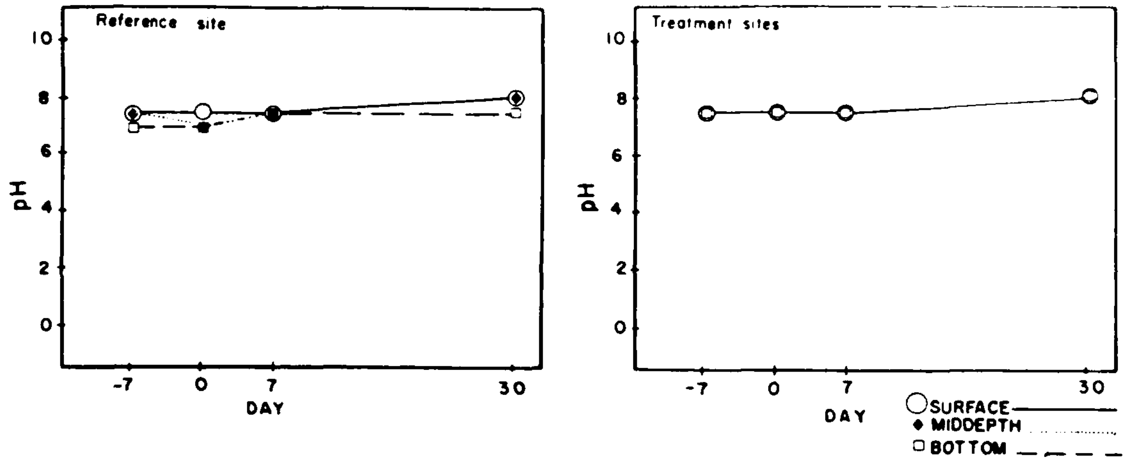


Figure 6. pH levels at the treatment sites and the reference site (control)

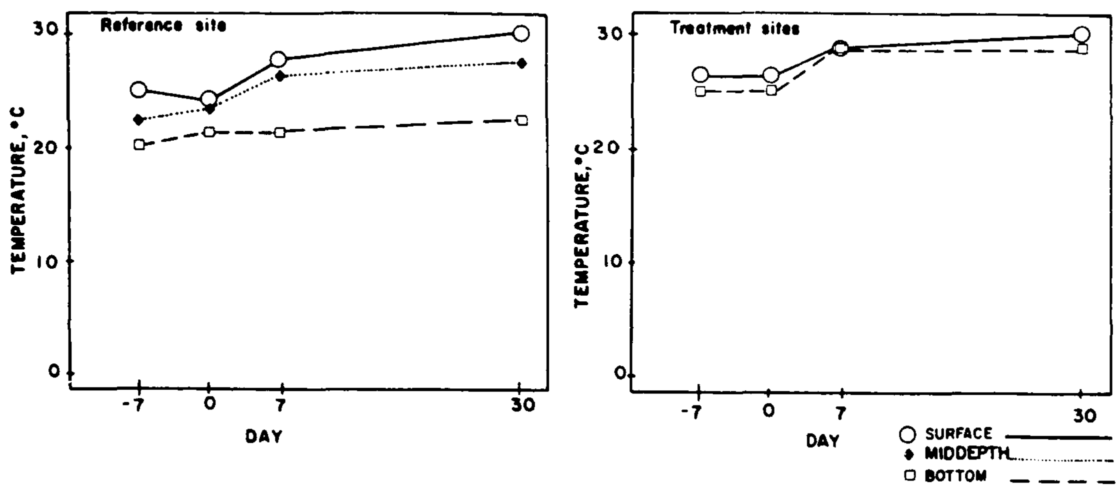


Figure 7. Temperature at the treatment sites and the reference site (control)

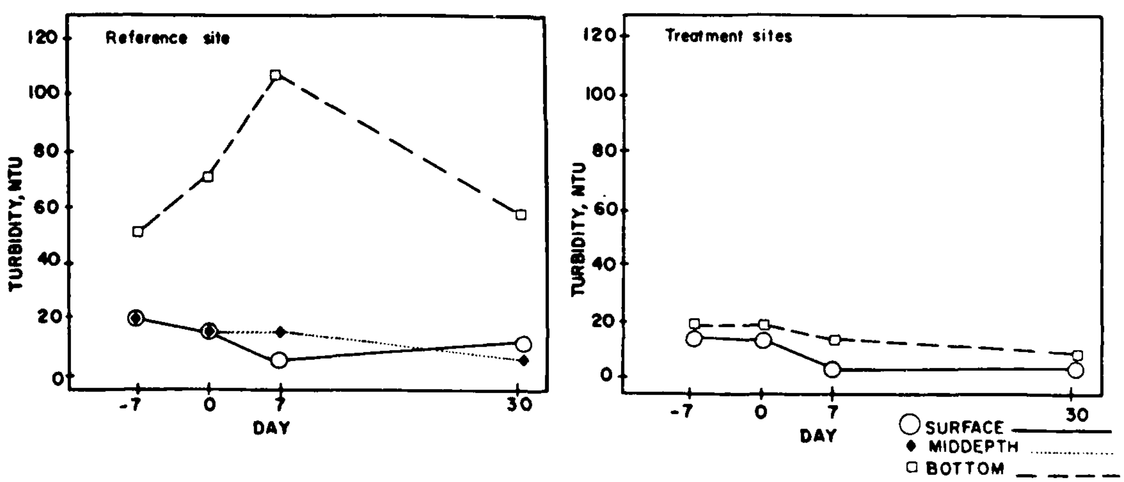


Figure 8. Turbidity at the treatment sites and the reference site (control)

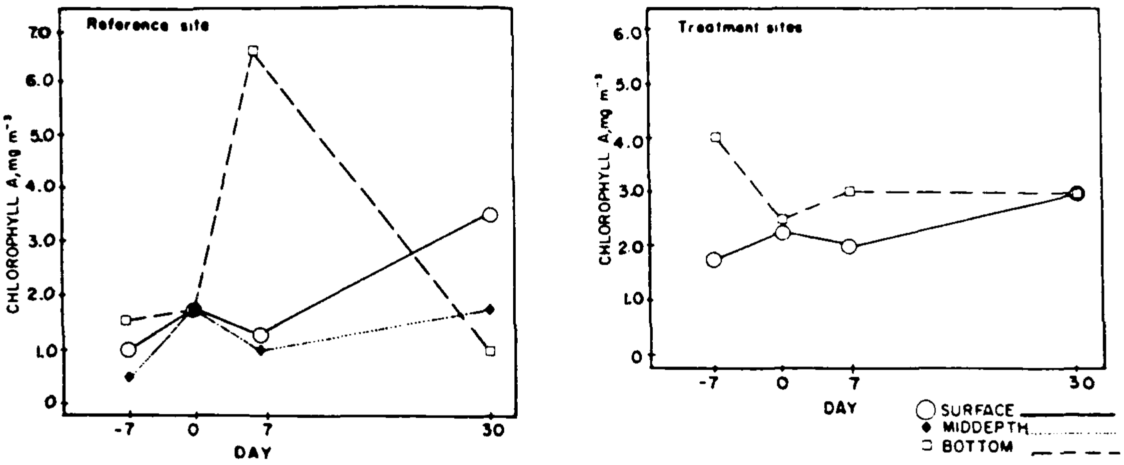


Figure 9. Chlorophyll *a* concentrations at the treatment sites and the reference site (control)

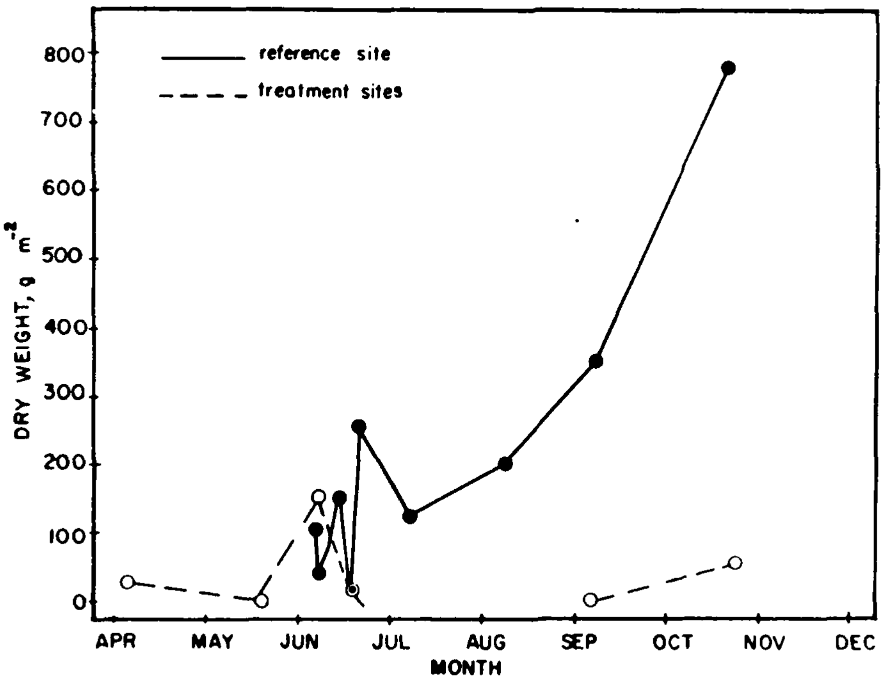


Figure 10. Biomass (dry weight) of watermilfoil at the treatment sites and the reference site (control)

e. The treatment program was apparently very successful. Approximately 100-percent control of milfoil was obtained in the treatment areas with no adverse effects observed.

Although Aquathol controlled the watermilfoil at the treated sites within Pat Mayse Lake, the use of herbicides to control aquatic vegetation is a temporary solution—a stop-gap measure that relieves the effects of the aquatic weed problem and returns the water body to its "full" usage capacity. (Florida Department of Natural Resources 1972). Even with proper application timing, herbicidal control of nuisance aquatic vegetation is a maintenance measure that almost always involves periodic retreatment due to plant regrowth and recruitment (Ohio Cooperative Extension Service, undated; Michigan Department of Natural Resources 1978).

REFERENCES

Armstrong, J. G. 1974. "A Review of the Literature on the Use of Endothall in Fisheries," U.S. Document PB-235 447, NTIS, Springfield, Va.

Carlson, R., Whitaker, R. and Landskov, A. 1978. "Endothall," *Analytical Methods for Pesticides and Plant Growth Regulators*, G. Zweig, ed., Vol X, Academic Press, New York, pp 327-340.

Chiou, C. T., et al. 1977. "Partition Coefficients and Bioaccumulation of Selected Organic Chemicals," *J. Agr. Food. Chem.* Vol 11, No. 5, pp 475-478.

Florida Department of Natural Resources. 1972. "Guidelines for Aquatic Weed Control," Tallahassee, Fla.

Grace, J. B., and Wetzel, R. G. 1978. "The Production Biology of Eurasian Watermilfoil (*Myriophyllum spicatum* L.): A Review," *J. Aqt. Plant Manage.*, Vol 16, pp 1-11.

Michigan Department of Natural Resources. 1978. "Aquatic Plants and Their Control," Division of Land Resource Programs, No. IC-4853.

Ohio Cooperative Extension Service. Undated. "Ohio Pond Management," Bulletin No. 374, The Ohio State University.

Pennwalt Corporation. Pennwalt sales literature; Endothall, Philadelphia, Pa.

Reinert, K. H., and Rodgers, J. H., Jr. "Influence of Sediment Types on the Sorption of Endothall," *Bull. Environ. Contam. Tox.*, In Press.

Rodgers, Jr., J. H., Hinman, M. L., and Reinert, K. H. 1982. "Pat Mayse Lake, Texas: Vegetation Mapping, Flow Measurement and Aerial Monitoring of Eurasian Watermilfoil," Report - Institute of Applied Sciences, Report to Tulsa District, CE.

Sikka, H. C., and Rice, C. P. 1973. "Persistence of Endothall in Aquatic Environment as Determined by Gas-Liquid Chromatography," *J. Ag. Food Chem.*, Vol 21, No. 5, pp 842-846.

Simsiman, G. V., Daniels, T. C., and Chesters, G. 1976. "Diquat and Endothall: Their Fates in the Environment," *Res. Rev.*, Vol 62, pp 131-174.

Veith, G. D., Defoe, D. L., and Bergstedt, B. V. 1979. "Measuring and Estimating the Bioconcentration Factor of Chemicals in Fish," *J. Fish Res. Bd. Can.*, Vol 36, pp 1040-1048.

AD-P003 597

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

South Atlantic Division, Mobile District

by
Michael J. Eubanks*

Activities during the past year in the Mobile District which relate to aquatic plant control deal with four geographical areas: Lake Seminole, Mobile Delta, Coffeeville Lake, and the Tennessee-Tombigbee Waterway. Lake Seminole will be discussed by Mr. Joe Kight; therefore, this paper is limited to the latter three areas.

MOBILE DELTA

Aquatic plant control activities in the Mobile Delta have been carried out for the past 3 years under contract with the Alabama Department of Conservation and Natural Resources. The primary target species is Eurasian watermilfoil which infests an estimated 3000 acres of the Delta waters. Minor treatments during the past year involved alligatorweed and pennywort. Approximately 1000 acres of milfoil were treated during the 1983 growing seasons (including retreatments) using 2,4-D in an effort to maintain small boat channels and fishing openings. The herbicidal applications provided about 60 days of control. An expansion of waterhyacinths in the Delta has been noted. Waterhyacinths, which have historically grown to problematic proportions, have not been widespread since Hurricane Frederic in September 1979. Its growth will continue to be monitored and negotiations are under way to expand the existing contract to include chemical and biological control efforts on waterhyacinth. Although no records of waterhyacinth weevil (*Neochetina* sp.) releases are known for the Mobile Delta area, insect damage recently discovered has been identified as waterhyacinth weevil damage.

COFFEEVILLE LAKE

Hydrilla control on Coffeeville Lake, a part of the Black Warrior-Tombigbee Waterway Navigation Project, showed very positive results during 1983. Combinations of Aquathol K and Nalquatic and Aquathol K and Cide Kick were applied to the hydrilla infestation that had grown to approximately 15 acres in past years. Inspection of the area in early October 1983 revealed only a volume of about 2.5 gal of hydrilla. This small quantity was removed by hand. Continued surveillance and control work, as necessary, will be carried out on Coffeeville Lake during 1984.

* U.S. Army Engineer District, Mobile; Mobile, Alabama.

TENNESSEE-TOMBIGBEE WATERWAY

Potential development of aquatic plant growth on the Tennessee-Tombigbee Waterway (TTW) has been speculated on by many and was a key item of discussion in the recently concluded litigation on that project. The following paragraphs summarize the aquatic plant situation on the TTW.

The Tennessee-Tombigbee Waterway was authorized for construction by Congress in the River and Harbor Act of 1946. The TTW will connect the north-flowing Tennessee River to the south-flowing Tombigbee River by a series of 10 locks and dams between Demopolis Lake in west-central Alabama and Pickwick Lake in northeast Mississippi. The overall length of the waterway is 233.6 miles which is composed of three distinct sections: River Section (149.3 miles), Canal Section (45.6 miles), and Divide Section (38.7 miles). The project, which is the largest Civil Works project ever built by the Corps, is approximately 80 percent complete and is scheduled for completion in September 1985.

The 10 lakes created by the TTW will increase the water surface acreage in the project area from about 4,500 acres to 44,000 acres. The eventual extent of infestation of this man-made aquatic habitat has been speculated on by many, including the recently concluded litigation. Table 1 presents pertinent data on the shallow-water areas that will exist within the TTW lakes. As shown, ample quantities of shallow-water habitat will be created by the TTW (20,000 acres less than 6 ft deep, 14,000 acres less than 4 ft deep, and 7,500 acres less than 2 ft deep).

Table 1
Shallow-Water Areas Within The TTW Lakes

		Surface Area (acres) Less Than		
Lake	*Total Surface Area, acres*	*2 ft Deep*	*4 ft Deep*	*6 ft Deep*
Gainesville	6,400	1,830	3,125	4,240
Aliceville	8,300	1,420	2,840	4,195
Columbus	8,910	1,910	3,710	5,180
Aberdeen	4,121	811	1,371	1,871
RIVER SECTION	27,731	5,971	11,046	15,486
Pool A	914	280	577	694
Pool B	2,718	414	827	1,213
Pool C	1,642	225	449	647
Pool D	1,992	133	267	390
Pool E	851	120	239	361
CANAL SECTION	8,117	1,172	2,339	3,305
Bay Springs	6,600	350	660	950
Divide Cut	1,045	28	56	84
DIVIDE SECTION	7,645	378	716	1,034
TOTAL TTW	43,493	7,521	14,101	19,825

A good estimate of the anticipated aquatic plant growth in these TTW lakes, at least initially, can be obtained by noting the species that existed in the project area prior to construction. A study by Miller et al. (1975) listed 19 species of aquatic plants collected along the route of the waterway. Common species included waterthread pondweed (*Potamogeton diversifolius*), coontail (*Ceratophyllum demersum*), fanwort (*Cabomba caroliniana*), muskgrass (*Chara* sp.), bladderwort (*Utricularia inflata*), giant duckweed (*Spirodela polyrhiza*), watershield (*Brasenia schreberi*), yellow waterlily (*Nuphar advena*), white waterlily (*Nymphea odorata*), pennywort (*Hydrocotyle ranunculoides*), parrotsfeather (*Myriophyllum brasiliiense*), bogmat (*Wolffiella floridana*), waterwillow (*Justicia americana*), burreed (*Sparganium americanum*), arrowhead (*Sagittaria latifolia*), waterleaf (*Hydrolea quadrivalvis*), hedge hyssop (*Gratiola neglecta*), mudplantain (*Heteranthera reniformis*), and smartweed (*Polygonum hydropiperoides*). The Tennessee Valley Authority reported three general herbaceous vegetation types within the Yellow Creek embayment of Pickwick Lake. The deepest growing vegetaion type (to depths of 2 ft below summer pool) was dominated by slender spikerush (*Eleocharis acicularis*) and blunt spikerush (*E. obtusa*). The second zone of grasslike vegetation, immediately above the spikerush zone, is characterized by species such as woolgrass (*Scirpus cyperinus*), rice cutgrass (*Leersia oryzoides*), frogbit (*Limnobium spongia*), soft rush (*Juncus effusus*), and various species of sedge (*Cyperus* spp.). The uppermost vegetative zone (about 0.5 ft below and above the mean summer pool) was composed primarily of marshmallow (*Hibiscus militaris*), beak rush (*Rhyncospora corniculata*), smartweeds (*Polygonum* sp.), lizardtail (*Saururus cernuus*), and cattail (*Typha latifolia*). Waterwillow was considered the species of greatest abundance and occurred in a frequent colonial growth pattern throughout the Yellow Creek embayment. The only submersed species encountered in the TVA study was a small colony of waterthread pondweed (*Potamogeton diversifolius*). The last recorded submersed aquatic plant problem in the Yellow Creek embayment was a small colony of coontail in October 1967. Slender naiad (*Najas minor*) and southern naiad (*N. guadalupensis*) have also caused problems historically but total growth has never exceeded 100 acres for the entire Pickwick Lake.

A number of aquatic plants which typically cause problems have been reported from or near the route of the waterway. Alligatorweed (*Alternanthera philoxeroides*) is probably the only exotic (not native to U.S. waters) aquatic plant that existed in the area before construction of the TTW began. Waterhyacinth (*Eichhornia crassipes*) exists in the lower Tombigbee River Basin but the TTW approaches the northern climatic boundary for this species. Eurasian watermilfoil is found in both the Tennessee and lower Tombigbee River systems, as well as the exotic water primrose (*Ludwigia uruguayensis*) although they have not been confirmed for the TTW. Hydrilla (*Hydrilla verticillata*), a very troublesome exotic aquatic plant, is found in Coffeeville Lake on the lower Tombigbee River and in Guntersville Lake on the Tennessee River. Also, spotty infestations of another potentially troublesome submersed exotic aquatic plant, slender naiad, are found in Pickwick Lake of the Tennessee River system and Coffeeville Lake on the lower Tombigbee River. Water level fluctuation within Pickwick Lake helps to minimize the growth of aquatic plants in this impoundment. Some of the major noxious aquatic plants within the Tennessee Valley include (in order of economic significance): Eurasian watermilfoil

(*Myriophyllum spicatum*), slender naiad, American pondweed (*Potamogeton nodosus*), various species of macroscopic algae (*Pithophora* spp. and *Cladophora* spp.), southern naiad, curly-leaf pondweed (*P. crispus*), egeria (*Egeria densa*), coontail, waterprimrose (*Ludwigia peploides* var. *glabrescens*), waterstargrass (*Heteranthera dubia*), duckweeds, sago pondweed (*P. pectinatus*), giant smartweed (*Polygonum coccineum*), Canadian elodea (*Elodea canadensis*), and waterpaspalum (*Paspalum fluitans*).

Completion of the three southernmost lakes has perhaps given us a better indication of the level of aquatic plant growth for the TTW. Gainesville, Aliceville, and Columbus Lakes have been impounded for 5, 3.5, and 2.5 years, respectively, and are developing extensive growths of native submersed, floating, and emergent aquatic plants in many of the shallow-water areas. A survey of Gainesville and Aliceville was carried out in August 1983. The vast majority of the aquatics were growing in waters less than 4 ft deep. All of the aquatic plant communities appear to be supporting excellent fish and waterfowl populations and no water quality related problems were observed. The "problem" with the current level of aquatic plant growth is one of small boat navigation. Since one of the project purposes of the TTW is recreation, navigation access by recreational craft is an important consideration for aquatic plant management on the waterway. A list of the plants observed during the survey and their relative abundance is presented in Table 2. The primary plant species involved include coontail, southern naiad, cabomba, duckweed, chara, American lotus, and waterprimrose. The only "exotic" species found was alligatorweed (two small patches on the lower Aliceville pool). There was evidence of stem borer moth (*Vogtia malloi*) damage on both patches of alligatorweed. Aerial photography (1:24,000, color infrared, September 1982) was utilized to obtain a quantitative estimate of the submersed and floating-leaved plants. Gainesville Lake contains an estimated 714 acres of submersed aquatics and 4 acres of American lotus. Aliceville Lake contains an estimated 1582 acres of submersed aquatics and 35 acres of American lotus. A summary of the survey is presented in Table 3.

Based on the findings of the August survey, a limited chemical control action was carried out in mid-September. Approximately 45 acres of submersed aquatics was treated with endothall in order to open some boat channels and fishing areas in the most heavily infested areas of Aliceville Lake. Follow-up inspections revealed good control in some areas and fair to poor control in others.

Observation of the survey data indicates that factors other than water depth are important in determining the extent of aquatic plant growth, at least initially. These other factors probably include water temperature, nutrient availability, wind and wave action, turbidity, water level fluctuation, substrate composition, flow, sedimentation, "seed stock" availability, and drainage order. Based on aquatic plant growth in Gainesville and Aliceville Lakes (11 and 19 percent coverage, respectively), an estimate of 20 percent surface area coverage would yield an ultimate areal extent of approximately 8700 acres for the TTW. Calculated another way, if 50 percent of the area less than 4 ft deep (currently 23 percent in Gainesville and 56 percent in Aliceville Lakes) were inhabited by aquatic plants, the areal extent for the TTW would be approximately 7000 acres.

In an effort to properly manage these aquatic resources, the Corps will continue to

Table 2
Aquatic Plants Found in Gainesville and Aliceville Lakes, 9-10 August 1983

Scientific Name	*Common Name*	*Abundance**	*Waterfowl Value***	*Fish Value***	*Type*
Cabomba caroliniana†	Fanwort	M	Low	Good	Submersed
Ceratophyllum demersum†	Coontail	A	Fair	Good	Submersed
Najas guadalupensis	Southern naiad	A	Excellent	Good	Submersed
Chara sp. †	Muskgrass	A	Excellent	Good	Submersed
Utricularia purpurea	Bladderwort	S	Low	Good	Submersed
Potamogeton pusillus	Pondweed	S	Good	Good	Submersed
Myriophyllum brasiliense†	Parrotsfeather	S	Fair	Good	Submersed
Spirodela polyrhiza†	Giant duckweed	A	Good	Fair	Floating
Wolffia columbiana†	Watermeal	A	Fair	Fair	Floating
Azolla caroliniana	Waterfern	S	Good	Fair	Floating
Nelumbo lutea	American lotus	M	Low	Good	Floating leaved
Brasenia schreberi†	Watershield	S	Good	Good	Floating leaved
Hydrocotyle sp.†	Pennywort	S	Low	Good	Floating mat
Alteranthera philoxeroides	Alligatorweed	S	Low	Fair	Floating mat
Ludwigia peploides	Waterprimrose	A	Fair	Fair	Floating mat
Polygonum sp.†	Smartweed	M	Excellent	Good	Emergent
Sagittaria sp.†	Arrowhead	M	Low	Fair	Emergent
Echinodorus cordifolius	Creeping burhead	S	Low	Fair	Emergent
Eleocharis quadrangulata	Squarestem spikerush	S	Good	Fair	Emergent
Typha sp.	Cattail	S	Low	Fair	Emergent
Justicia americana†	Waterwillow	S	Low	Fair	Emergent
Hydrolea sp.†	Waterleaf	S	Low	Fair	Emergent

* A - Abundant
M - Moderate
S - Scarce

** Source: Martin, Zim, and Nelson (1951), Martin and Uhler (1939), and Fassett (1940).

† Recorded in preimpoundment aquatic plant surveys by Miller et al. (1975)

Table 3
Tennessee-Tombigbee Waterway
Aquatic Plant Survey*

Site	*Submersed, acres*	*American Lotus, acres*
	Aliceville Lake	
Aliceville Lock and Dam Area	30	3
Pickensville Backwater Area	697	—
Bigbee Valley Area	89	9
Coal Fire Creek Area	140	3
Broken Pumpkin Creek Area	232	—
Area South of Hairston Cutoff	195	20
Hairston Bendway Area	199	—
	1,582	35
	Gainesville Lake	
Turkey Paw Creek Area	98	2
Sumter Recreation Area	52	—
Wilkes Creek Area	388	—
Warsaw Cutoff Area	41	1
Cooks Bend Cutoff Area	22	—
Oxbow Area South of Windham Landing Cutoff	94	1
Windham Landing Cutoff Area	19	—
	714	4

* Based on August 1983 field survey supplemented with aerial photography.

monitor aquatic plant growth. Ground surveys in additon to semi-annual aerial photography will help to understand the plant growth dynamics within the overall TTW lakes.

REFERENCES

Fasset, N. C. 1940. *A Manual of Aquatic Plants.*

Martin, A. C., Zim, H. S., and Nelson, A. L. 1951. *American Wildlife and Plants; A Guide to Wildlife Food Habits.*

Martin, A. C., and Uhler, F. M. 1939. *Food of Game Ducks in the United States and Canada.*

Miller, et al. 1975. "An Ecological Study of the Tennessee-Tombigbee Waterway."

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

South Atlantic Division, Mobile District, Lake Seminole

by
Joe Kight*

The following is a brief summary of aquatic plant control activities at Lake Seminole during the 1983 season.

HYDRILLA

Approximately 643 acres of hydrilla were treated by helicopter application during May with Aquathol K®mixed with the surfactant Nalquatic® at rates of 7 gal and 0.2 gal, respectively, per surface acre. The area of treatment was generally the north-central portion of Lake Seminole in the Fish Pond Drain-Spring Creek areas. Damage to plants was evident within 7 to 10 days. Virtually all visible hydrilla in the treated areas disappeared within 25 days. The duration of control was directly proportional to water depth as follows: 0-4 ft, 1 to 2 months of control; 4-7 ft, 2 to 3 months of control; and ≥ 7 ft, 3 to 4 months of control. Areas with water depth of 7 ft or less (most small boat channels) would require at least two treatments to provide seasonal control.

EURASIAN WATERMILFOIL

Approximately 500 acres infected with this plant was treated in May 1983 with Aquathol K® and Nalquatic® at the 7/0.2 rates mentioned for the hydrilla treatments. The area treated for Eurasian watermilfoil control was principally in Spring Creek from its opening to Lake Seminole proper to the north. Plants dropped out within 14 days in the treated area. A second dropout occurred in the south end of Spring Creek at approximately 25 days after treatment. Regrowth occurred in most treated areas but about 80 percent of these areas remained navigable by small boat traffic throughout the summer and fall recreation season. Generally, in areas of reduced water flow control was of longer duration.

GIANT CUTGRASS/WATERHYACINTH

Since these two species grow in mixed stands or contiguous to one another, they were treated during the same operation using the same chemical mixture. The plants were sprayed from an airboat with a mixture of 1.25 gal of Rodeo® and 0.25 gal X-77® surfactant per acre. A total of about 800 acres was treated. That herbicide mixture appeared to be about 60 percent effective on cutgrass and only 25 percent

* U.S. Army Engineer District, Mobile; Chattahoochee, Florida.

effective on waterhyacinths. Operators suggest that most of the problems with this treatment resulted from physical difficulties of mixing the herbicides and surfactant and from difficulties of placing the herbicide mixture on target in the amounts required for control. Observations of this operation did indicate that cutgrass treatments in early fall (September) showed more positive effort toward control than at other times.

OTHER STUDIES

Two demonstration trials were performed on the control of hydrilla, one with Sonar® and the other with Diquat®. Two 10-acre plots and one 4-acre plot were treated with Sonar® at the recommended rate using a tank mix sprayed on the surface of the plots from an airboat. The plots were located in Ray's Lake which is a 230-acre lake connected to Lake Seminole by a 200-ft channel. The area was 90-95 percent infested with hydrilla averaging 1-2 ft below the water's surface. Signs of herbicidal effect were evident within 10 days after treatment with growing tips of hydrilla becoming chlorotic. At 25 days posttreatment, the above signs had spread to the entire lake with growing tips of most hydrilla plants eliminated. At 50 days posttreatment, all hydrilla in the lake appeared stressed but none had actually dropped out. At 110 days approximately 50 acres of hydrilla had dropped out and the remainder appeared headed in that direction. The cleared area was not immediately within one of the plots treated initially but adjacent to one of them in the center of the lake in a water depth of 6 to 12 ft. Some general observations of this test were that the herbicide acts extremely slow when applied in midsummer. In early fall about 50 acres of hydrilla had been eliminated in Ray's Lake. Long-term control will be evaluated over the winter of 1983-1984. The spread of herbicidal effects indicates the large amount of water flow which is generally typical of Lake Seminole. That condition also points to the general problem of herbicide/target plant contact time which is currently a major concern among aquatic plant control operators. Tentative results, therefore, indicate that Sonar® may have some future application at Lake Seminole. Additional trials will be undertaken in FY 84.

Some additional trials were made in the Cypress Pond-Spring Creek area with four mixtures using the herbicide Diquat®. Eight 1-acre plots with two replications each of: 1.5 gal Diquat® + 2 gal Cutrine®; 1.5 gal Diquat® + 1 gal Aquathol K®; 2.0 gal Diquat®; 2.0 gal Diquat® + 0.4 gal Nalquatic®; and one 1-acre plot of 1.5 gal Diquat® + 2 gal Aquathol K® were treated by airboat with a tank mix of the herbicides using subsurface application. The results on all plots were that hydrilla was killed back to the substrate within 10-12 days and regrowth occurred within 30-40 days. It appears that two or three applications would be necessary for seasonal control using any of these herbicide combinations.

USAE DIVISION/DISTRICT PRESENTATIONS AQUATIC PLANT PROBLEMS—OPERATIONS ACTIVITIES

Southwestern Division, Galveston District

by
Joyce Johnson*

The Galveston District is part of the Southwestern Division and is located along the entire Texas gulf coast. Our District is responsible for the aquatic plant control program throughout the state, except in Corps project areas where each District Office is responsible for its particular areas as part of the operations and maintenance programs.

The Aquatic Plant Control Program has been active in Texas since 1968. A General Design Memorandum and an Environmental Statement were distributed in 1971 and 1972, respectively, covering the operations of the Texas program. During this 15-year period, the Corps has had three successive contracts with the Texas Parks and Wildlife Department, who represent the State of Texas as project sponsors. The Parks and Wildlife Department does all the control work for alligatorweed and waterhyacinth, the two species authorized for control in Texas. The control of waterhyacinth is by chemical spraying of 2,4-D (2,4-dichlorophenoxyacetic acid), generally by boat crews. Alligatorweed is controlled by the *Agasicles* flea beetle which has been released periodically in the state as overwintering and water fluctuation problems occur. A draft supplemental General Design Memorandum and Environmental Statement to include treatment of hydrilla and Eurasian watermilfoil are substantially complete, but have not been finalized for initiation of the review process, primarily due to lack of funds and personnel during the last 3 years.

The Texas Parks and Wildlife Department does all the fieldwork for the Galveston District. Operating mainly from March through September each year, seven crews are located in the state operating from four locations. The state is divided into 18 work areas, generally divided by river basins. Twelve of the eighteen work areas have plant problems sufficiently large to warrant active control. The areas are generally within 200 miles of the gulf coast.

During the spring and summer of 1983, the State crews treated nearly 17,000 acres of plants, primarily waterhyacinth. Of this acreage, 5,000 acres were treated by aerial spraying using a State Department of Corrections helicopter at a nominal cost to the program. This is the first year major use of aerial spraying has been accomplished.

During the past 3 years, the Galveston District has sponsored additional biological control efforts in an attempt to have a more environmentally sensitive and cost-effective program. The U.S. Army Engineer Waterways Experiment

* U.S. Army Engineer District, Galveston; Galveston, Texas.

Station was contacted in 1979 to survey the existing biocontrol agents in Texas and to introduce additional control species, establish nursery areas, monitor the effectiveness of each species for the Texas area, and prepare a management report for the District's use for biological control agents in unsprayed, generally inaccessible areas. The following species were introduced in Texas: *Neochetina eichhorniae*, *Neochetina bruchi*, and *Sameodes albiguttalis* on waterhyacinth, *Amynothrips andersoni* on alligatorweed, and an experimental application of the pathogen *Cercospora rodmanii* on waterhyacinth. The biological control effort has been very successful. Dr. A. F. Cofrancesco, WES, has prepared a more detailed summary of the work in Texas, which will be presented later in the program.

The Aquatic Plant Control Program is alive and flourishing in Texas. As a result of the last two mild winters, the plants have been a bigger problem than anticipated and, therefore, funding is often a problem. Preparing a budget 2 years before the extent of the problem is known can be a real challenge.

MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

Development of Simulation Models for Prediction of Performance, Effectiveness, and Cost of Aquatic Plant Control Methods and Procedures

by
H. Wade West*

The development of simulation models will provide the analytical tools required to permit the Corps of Engineers (CE) to determine the performance, effectiveness, and cost of mechanical, chemical, and biological control operations for the purpose of controlling floating, submerged, and emergent aquatic plants in waterways (rivers, canals, and lakes). Simulation models provide an analytical means for determining how environmental parameters such as water depth and flow conditions, plant type, and plant biomass density affect overall operational treatment parameters such as chemical dosage rates, insect population levels, or mechanical harvesting rates. These models, once developed, will allow realistic simulation of any specific control method operating in any aquatic plant infested environment.

Two simulation models have already been developed under the CE Aquatic Plant Control Research Program (APCRP). These include HARVEST, a simulation of mechanical control operations, and STOCK, a simulation of white amur stocking rates for biological control operations.

During FY 83 work was initiated on conceptualizing a new analytical procedure for predicting the effectiveness of various aquatic plant control methods and procedures. This procedure will include the use of both the HARVEST and STOCK models as well as several other computer models and/or algorithms that will be developed for simulation of other treatment methods and procedures.

The following paper by Mr. Hutto describes the new algorithms that have been developed and incorporated into the HARVEST model and also demonstrates how the model output can be used for planning operational control programs. The paper by Mr. Sabol provides an illustration and description of the first-generation methodology for predicting effectiveness of selected aquatic plant control operations.

During FY 84, WES will be transferring the HARVEST and STOCK simulation models to other Districts, Divisions, and industries in the private sector. Other models currently under development will be transferred once they have been completed and verified.

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

AD-P003 598

MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

Demonstration of Utility of HARVEST Model

by
Tommy D. Hutto*

INTRODUCTION

The HARVEST computer model was developed under the Mechanical Control Technology area of the APCRP. This past year, algorithms to calculate the total cost of a mechanical harvesting operation, including the determination of the optimum number of trucks needed for land disposal, have been added. Changes to allow simulation of all commercially available harvesting systems have also been implemented. This paper briefly describes the utility of the model in its present form.

The HARVEST model has been described elsewhere** so only a brief discussion of the model will be presented. Recent modifications and additions to the model are also described and a demonstration of the utility of the model in its present form is presented.

MODEL INPUTS

Equipment

Equipment characteristics determine the speed at which the plants are removed from the water and delivered to the shore takeout points. These inputs are shown in Table 1.

Environmental parameters

The most important environmental parameter is plant density. Plant density determines the rate of movement of a particular harvester within the water body and the number of loads of material that must be transported to shore to clear an infested area. For optimum harvester productivity, plant density needs to be above some minimum level, such that the harvester's collection rate is only limited by its throughput (Table 1) and not by its cutter width or maximum working speed.

Other inputs

The distance to the shore takeout point from the harvesting site is an important input since this distance determines whether the harvesting operation is slowed because it must wait on a transport. The distance from the shore takeout point to the land disposal site determines the optimum number of trucks needed so as not to delay the harvesting operation.

---

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

** Hutto, T. D. 1982. "Simulation Modeling of Mechanical Control Systems," *Proceedings, 16th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review*, Miscellaneous Paper A-82-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 33-50.

Table 1
Inputs to HARVEST Model

Equipment characteristics
Cutter width, ft
Harvester maximum speed, ft/min
Harvester throughput, tons/hr
Harvester turning time, min
Transport unit changing time, min
Transport unit capacity, tons
Transport unit speed loaded, ft/min
Transport unit speed empty, ft/min
Unloading rate of transport unit, tons/min
Environmental parameters
Plant density grid array or average plant density, tons/acre
Other inputs
Distance from site corner nearest disposal site to disposal site, ft
Plot corner nearest disposal site
Docking time at shore takeout point, min
Distance from shore takeout point to land disposal site
Equipment rental rates for each piece of equipment used

MODEL OUTPUTS

The model outputs are shown in Table 2. The most useful outputs are the total harvesting time, harvesting costs, and the optimum number of trucks needed. Harvesting cost/acre includes costs of harvesting, transporting, and land disposal (trucking).

Table 2
Outputs of HARVEST Model

Harvester speed for each swath, ft/min
Harvester time for each swath, min
Plant material harvested for each swath, tons
X- and Y-location of each filled transport unit in site
Total harvesting time, min
Total harvesting time including turning time, transport time, and disposal time, min
Time harvester is waiting for transport unit, min
Total areal production of system, acres/hr
Total material production, tons/hr
Total plant material harvested, tons
Optimum number and size of trucks required to prevent lost time to harvesting operation
Cost of harvesting, transporting, and land disposal

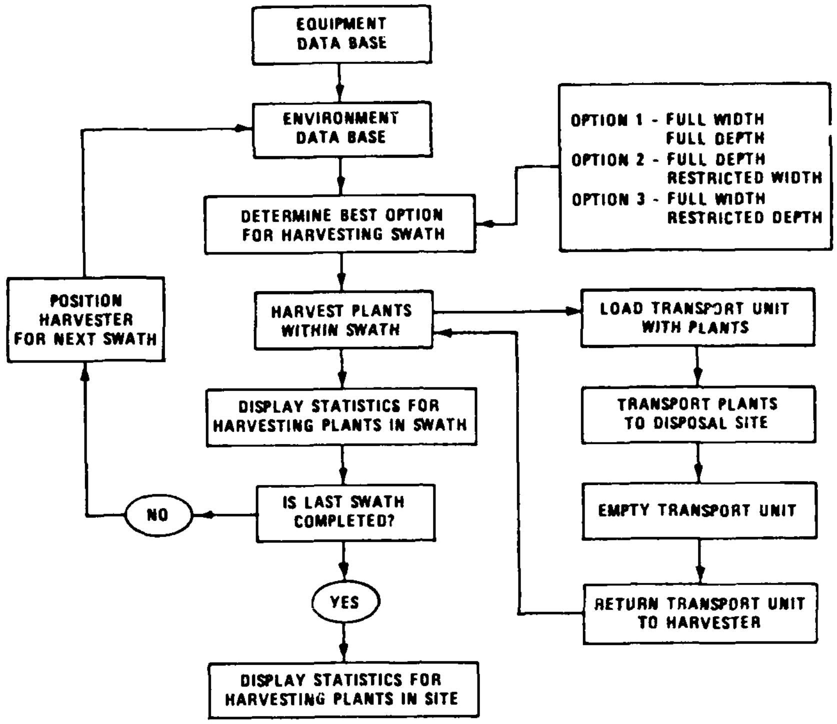


Figure 1. Generalized flowchart for HARVEST model

LOGIC OF THE MODEL

The logic of the model is shown in Figure 1. Using the equipment characteristics and environmental data base, the model determines the speed at which the harvester can operate based on the plant density within the first swath to be harvested. If the plants are too dense to harvest using the full cutter width, i.e. harvester cannot travel at minimum acceptable speed, then the cutter width is reduced until an acceptable speed can be reached. At very high plant densities, combinations of reduced cutter width and depth must be employed. This procedure then continues on a swath-by-swath basis until the site is harvested. The harvester-transport interaction is simulated and transport arrivals at the harvester and at the shore takeout point are predicted.

ADDITIONS AND/OR MODIFICATIONS TO HARVEST

This past year a simple cost routine and a trucking routine were added to the model. In addition. modifications were made to the model to allow simulation of additional sytems and/or mixes of equipment.

Cost routine

The cost routine uses hourly rental cost of various harvesters, transports, and trucks (model input) to determine the cost for the total harvesting operation. Rental rates tend to vary from place to place; therefore, total cost estimates output by the

model should not be treated as absolute values. However, relative differences in cost-effectiveness can be inferred from comparisons between different equipment mixes.

Trucking routine

The trucking routine uses the arrival time of the transports at the shore takeout point to calculate the number of trucks needed to avoid delays in the harvesting operation, i.e. so that the transport does not have to wait on a truck. Trucks of three conventional size capacities are modeled in the routine.

Other model modifications

Changes have been made to the model to permit simulation of any harvesting systems that removes plants from the water and transports the material to the shore, either with separate transports or by using the cutter-harvester as a transport, or any system that processes the material and returns it to the water body.

MODEL DEMONSTRATION

Simulated conditions

The model was used to predict performance for three different equipment mixes, seven different plant densities, and two different transport and land disposal conditions (Tables 3 and 4). The transport and land disposal conditions depict long barging/short trucking distances and short barging/long trucking distances. The purpose of these runs was to show that the model can be used to determine the most cost-effective and/or time-effective (minimum total operational time) equipment mixes and the optimum number of trucks needed.

The equipment mixes used are shown in Table 3. All three equipment mixes use the same cutter-harvester unit. However, in Mix 1, the cutter-harvester also transports to shore, while in Mixes 2 and 3, one or two separate transports, respectively, are used and the harvester does not serve as a transport. In all three

Table 3
Equipment Mixes Simulated with HARVEST

Mix 1
1 combination cutter-harvester (used for transport also)
1 on-shore conveyor
Mix 2
1 combination cutter-harvester (not used for transport but has holding capacity)
1 transport unit
1 on-shore conveyor
Mix 3
1 combination cutter-harvester (used same way as in Mix 2)
2 transport units
1 on-shore conveyor

Table 4
Equipment Characteristics and Operational Conditions

Equipment characteristics	
Cutter width - 8 ft	
Harvester maximum speed - 176 ft/min	
Harvester throughput - 15 tons/hr	
Harvester turning time - 0.5 min	
Transport unit changing time - 2 min	
Transport unit capacity - 4 tons	
Transport unit speed loaded - 230 ft/min	
Transport speed empty - 260 ft/min	
Unloading rate at transport unit - 1.0 ton/min	
Docking time at shore takeout point - 3.0 min	
Number of separate transports	
System 1 - 0	
System 2 - 1	
System 3 - 2	
Environmental parameters	
Site size - 35.44 acres	
Site dimensions - 1500 ft × 1000 ft	
Plant densities - 4, 8, 12, 16, 20, 24, 28 tons/acre	
Barging and trucking conditions	
Long barging/short trucking:	
Barging distance - 3000 ft	
Trucking distance - 1300 ft	
Short barging/long trucking	
Barging distance - 420 ft	
Trucking distance - 6000 ft	

mixes, the cutter-harvester has its own holding capacity; this permits the harvester in Mixes 2 and 3 to continue harvesting while the transport(s) are going to and from shore. All other inputs used are shown in Table 4.

Results

Model predictions for the total operational time and cost for the two transport-disposal conditions as a function of plant density are shown in Figures 2-5.

Long barging/short trucking. The most time-effective mix, as might be expected, is Mix 3 since the two transports greatly reduce total operational time as compared to Mixes 1 and 2 (Figure 2). Mix 2 is more time-effective than Mix 1 since the extra transport permits better utilization of the harvester.

The most cost-effective mix is also Mix 3 (Figure 3). However, the costs of using Mix 1 or 2 are almost the same with Mix 2 slightly more expensive.

Short barging/long trucking. Total operational times for Mixes 2 and 3 are virtually the same (Figure 4). This indicates that the extra transport in Mix 3 is not needed at the short barging distance. The transport in Mix 2 does allow greater utilization of the harvester than in Mix 1 where the harvester acts as a transport and is unproductive as a harvesting device during transport activities.

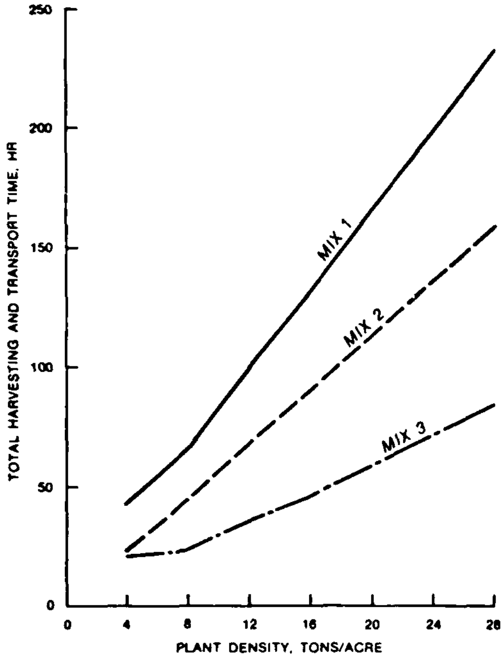


Figure 2. Operational time for long barging/ short trucking

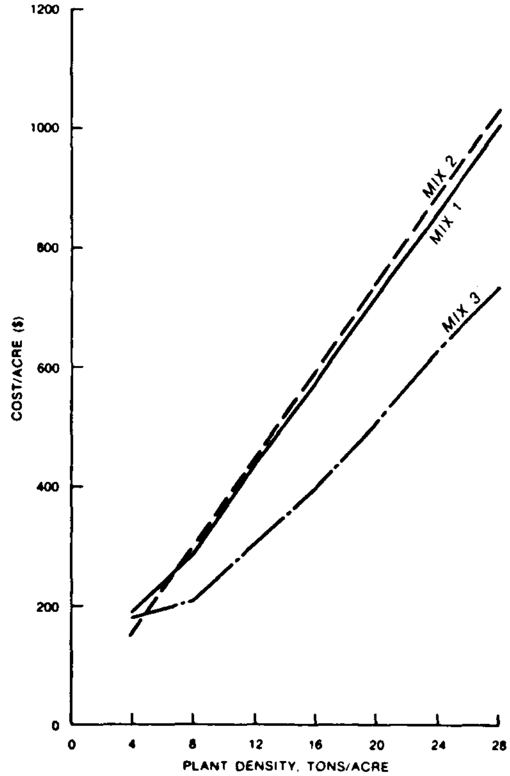


Figure 3. Operational cost for long barging/ short trucking

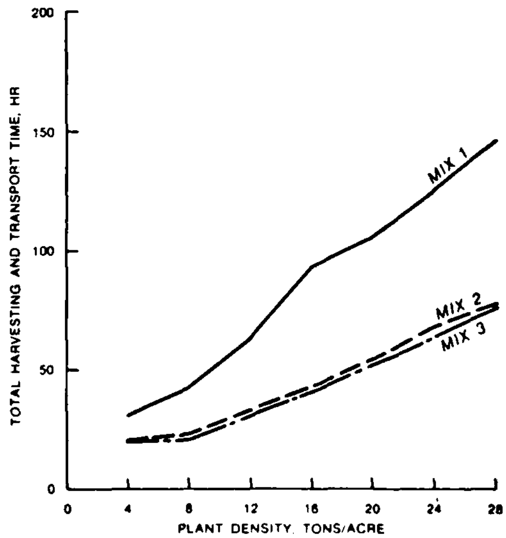


Figure 4. Operational time for short barging/ long trucking

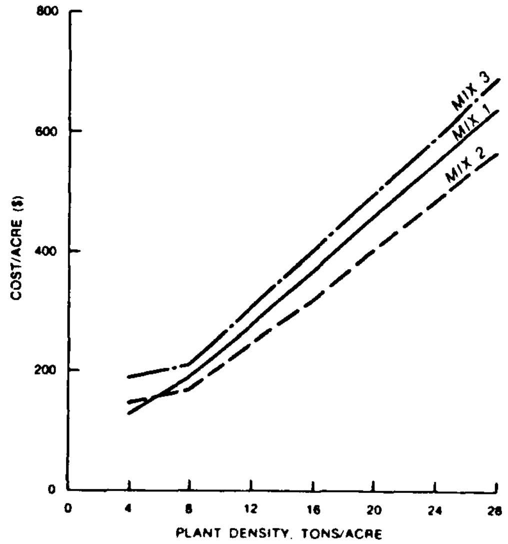


Figure 5. Operational costs for short barging long trucking

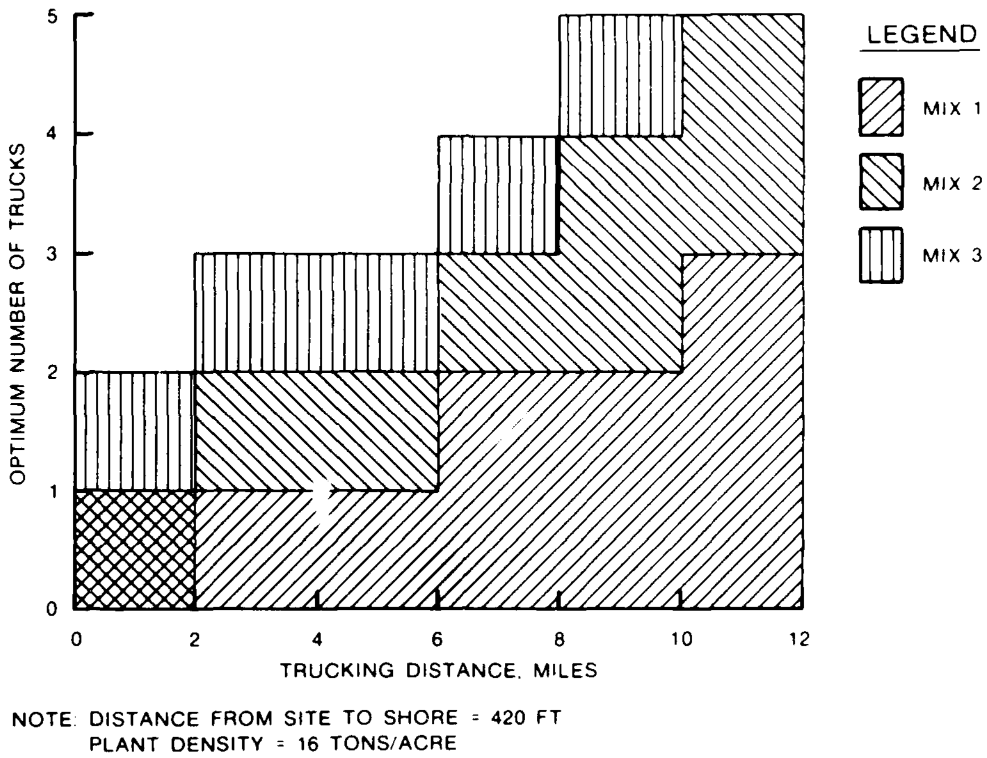


Figure 6. Optimum number of trucks by mix for variable trucking distances

The most cost-effective mix is Mix 2 and the least cost-effective is Mix 3 (Figure 5). This shows that the cost of the separate transport in Mix 2 is justified but the extra transport in Mix 3 is not.

Optimum trucking. The model was used to show how equipment mix and trucking distance affect the optimum number of trucks required. Simulations were run for the three mixes using a density of 16 tons/acre, a short barging distance of 420 ft, and trucking distances of 2, 4, 6, 8, 10, and 12 miles. Figure 6 illustrates the utility of the model in selecting the number of trucks needed to optimize the harvesting operation.

SUMMARY

The HARVEST model can be used to assist in planning harvesting and disposal operations. Although the model predicts "best case" times and costs, the results can be used to choose optimum equipment and land disposal mixes for a given plant infestation.

PLANS FOR FY 1984 WORK

During FY 1984, developmental work on HARVEST will be completed. An operational-planning version of the model, which will run on a personal computer and will have interactive graphic capabilities, will be released, along with a user's manual and appropriate documentation.

MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

Conceptual Development of Methods for Determining Effectiveness of Control Techniques

by
Bruce M. Sabol*

INTRODUCTION

From the time a real or potential aquatic plant infestation problem is identified to the time control measures are selected and implemented, information and data on the infestation condition must be obtained and assimilated, and decisions must be made in regard to the operational control program. If a potentially troublesome aquatic plant infestation, such as the discovery of hydrilla in a previously uninfested water body, is identified but the conditions are such that it is below the nuisance level, one must determine what treatment, if any, should be used. If the aquatic plant infestation is already at nuisance levels, the specific nature of the problem must be defined by determining what uses of the water body are being impeded. There is a need to determine at what level of control the infestation would no longer interfere with these uses and this in essence becomes the tentative "treatment goal." The next step is to determine what treatment technique to apply (and to what degree) to achieve the goal. The most commonly used means of determining this is through reliance on personal experience since there is no objective procedure for comparing candidate control techniques and treatment levels based on environmental conditions. One normally selects a specific technique and treatment level, and then proceeds with the control operation. The subjectively observed results of the applied treatments are added to one's personal experience.

In the above subjective procedure there are clearly several areas where better guidance and procedures are needed in making treatment decisions. There is a need to determine the "infestability" of a water body. For example, if a potentially troublesome aquatic plant species should become established in a particular water body, there is a need to determine when a nuisance condition would occur assuming no treatment is applied. The unique environmental conditions of the water body may not be sufficiently suitable to allow the species to reach problem levels, and therefore control efforts might not be needed. On the other hand, environmental conditions may be optimal for the plant, and a delay in initiating a control program might enable the plant to rapidly spread throughout the water body resulting in a more costly control program.

There is also a need to determine the most cost-effective treatment technique and level. No procedures currently exist which allow comparison of candidate treatment techniques and levels in order to select the most cost-effective treatment. Additionally, there is no means of estimating how long the treated plants will remain below nuisance levels as the result of the selected treatment.

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

CURRENT RESEARCH

Current research goals within the APCRP are addressing most of these needs. Research on the basic ecology of nuisance aquatic plant species should define the relationships between important environmental conditions and the growth potential of nuisance aquatic plant species. Once developed, this information will be integrated into a predictive methodology which will allow determination of how susceptible a specific water body is to infestation by a specific aquatic plant species by determining the growth rates for that species in that particular environment. This type of information will allow better assessment of treatment actions before the water body becomes infested.

Research on the development of improved chemical, biological, and mechanical control techniques will be incorporated into interactive computer simulation models. These models will provide a procedure to determine what degree of control is achievable with a specific treatment technique, the time for the plants to again reach nuisance levels, and the cost for applying the treatment. With these analytical tools one could play "what if" games, by simulating different treatment scenarios and determining the most cost-effective control to meet a particular management objective.

In order for the control technology research to culminate in these models, it will be necessary to develop various cause/effect relationships between the treatments and the response of the targeted plants. This requires that precise measures of plant response, i.e. data on the difference between plants before and after treatment, be obtained. These data must then be analyzed to quantify various measures of effectiveness of the particular treatments.

CONCEPT OF CONTROL METHOD EFFECTIVENESS

Assume for the moment that all important characteristics of a plant population in a given water body are known throughout the growing season; this information is illustrated in Figure 1. The vertical axis in Figure 1 represents some "defined" relative measure of infestation level. Further assume that there is some infestation level above which the plants interfere with the intended use of the water body and this is defined as the "threshold nuisance level." The threshold nuisance level may be defined in any number of ways and depends on the type of water body and its uses. Table 1 provides some hypothetical examples.

The concept of a *threshold* nuisance level implicitly assumes that all values above the threshold are equally bad and that all values below it are equally good. This obviously is not strictly true in all cases. For water body uses in which it is possible to choose whether or not the water body will be used, such as recreational uses, the concept of a threshold is valid. For water body usages for which no such choice exists, such as using the water body for domestic water supply once the intake plant has been constructed at the site, the problems caused by increasing plant infestation level are probably more a linear type relationship than a threshold type relationship. However, even in this example, a nuisance level could be defined above which it is impractical or too costly to use the water intake plant.

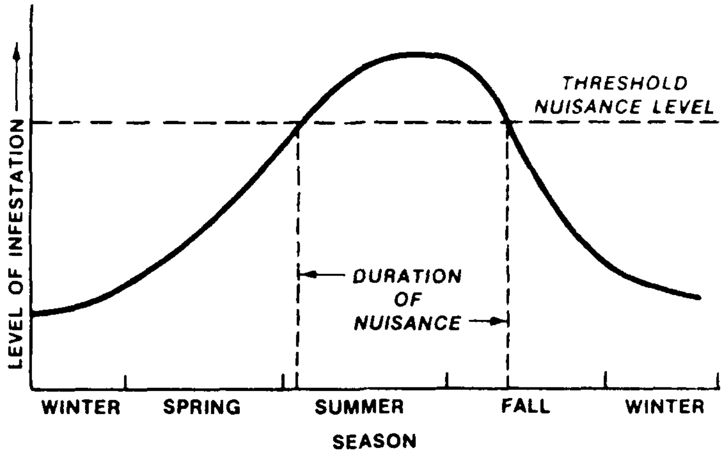
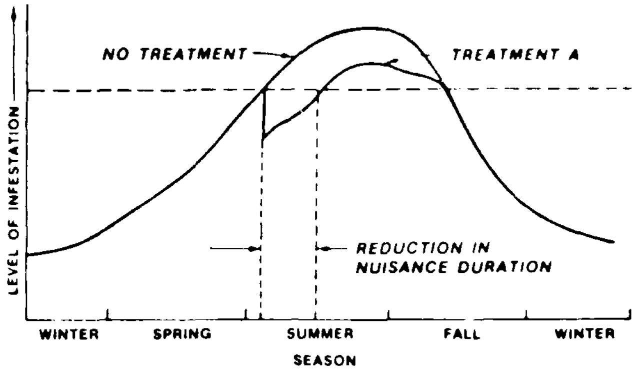


Figure 1. Hypothetical seasonal growth curve for an aquatic plant infestation

Table 1
Examples Of Threshold Nuisance Level

Water body		Infestation	Problem	Threshold
Type	Use	Type	Created	Nuisance Level
Lake	Boating	Submersed	Interferes with boating	Biomass > 3 tons acre in top 2 ft
Lake	Water supply	Submersed	Water quality degradation during fall	Surface topped growth covers > 10% lake area
Canal	Flood control	Submersed	Flow restriction	Biomass > 10 tons acre

Once the threshold nuisance level is defined, duration of the nuisance (that is the amount of time that the infestation condition is above the threshold nuisance level) may be determined (Figure 1). If a control treatment is then applied, such as the hypothetical treatment illustrated in Figure 2, the duration of the nuisance would be reduced from that which would occur without treatment. In a purely operational sense, the reduction in the duration of nuisance would be a measure of effectiveness, i.e. the number of days the applied treatment alleviated the nuisance conditions. This procedure would then be taken a step further by determining cost of the treatment. If the per acre treatment cost is divided by the reduction in nuisance duration, a direct measure of cost-effectiveness is determined by units of dollars per acre per day.



EFFECTIVENESS OF TREATMENT A = REDUCTION IN NUISANCE DURATION (RD)

COST EFFECTIVENESS OF TREATMENT A = $\frac{\text{COST OF TREATMENT A}}{\text{RD (DAYS)}}$

Figure 2. Effects of hypothetical treatment of an aquatic plant infestation

DEMONSTRATION OF CONCEPT

To test and demonstrate this concept, two first-generation analytical models were selected. These include the WES hydrilla growth model, BIOGROW, and the mechanical control simulation model, HARVEST.

BIOGROW, originally conceptualized and described by Miller (1981), simulates daily standing crop production of hydrilla. The model simulates the elongation and branching of hydrilla stems as a function of light and water temperature; the primary growth algorithm was developed from laboratory tests on hydrilla growth conducted by Barko et al. (1980) and includes the effects of self-shading of the hydrilla, "carrying capacity" effects, and natural senescence.

The BIOGROW model was used and predictions were obtained using inputs and initial conditions (Table 2) representative of water bodies in central Florida (obtained from WES data files). The results of the simulation for the total standing crop (grams per square metre) in the top 2 ft of the water column are presented in Figure 3. In this example, the threshold nuisance level was set at 500 g/m^2 and represents only the biomass in the top 2 ft of the water column; this was assumed to

Table 2
Environmental Inputs Used in BIOGROW Model Simulation

Water depth: 5 ft
Initial plant conditions
Stem density = 100 stems/m^2
Stem height = 0.5 ft
Water temperature conditions
Minimum = 10° C
Maximum = 30° C
Date of maximum temperature - 1 August
Water transparency (wavelength of 400-700 nm)
Extinction coefficient - 1.00 m

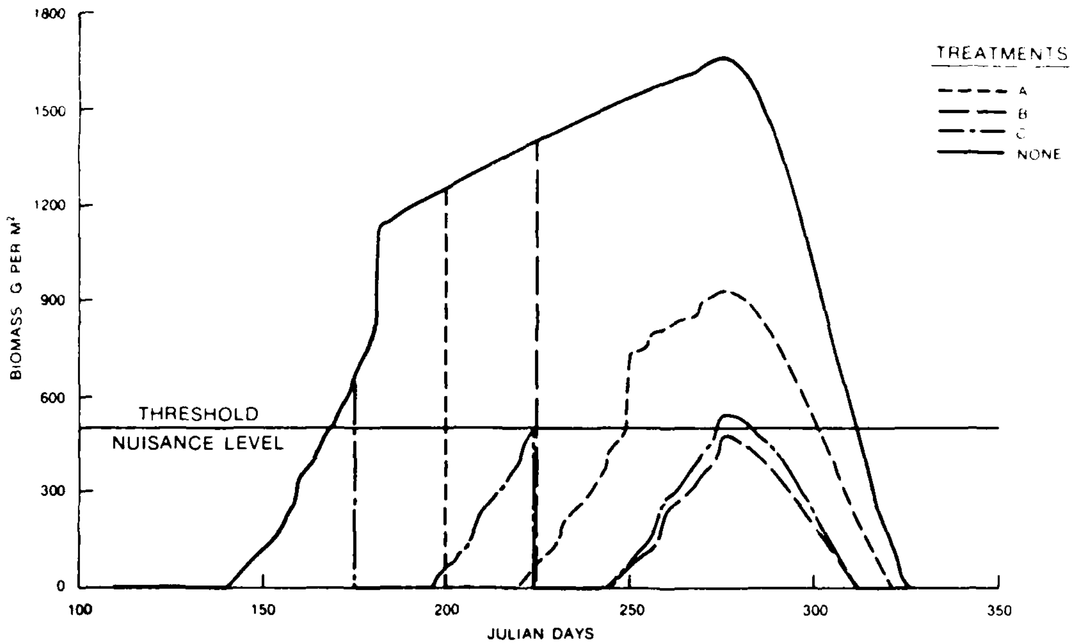


Figure 3. Effectiveness comparison of three selected harvesting treatments

be an appropriate level for a water body used principally for recreational boating in which high plant density near the water surface would interfere with boats powered by outboard motors. At this defined threshold nuisance level, the annual duration of nuisance is 143 days.

In addition to the no-treatment prediction (top curve in Figure 3), three different specific mechanical harvesting treatments were simulated. Treatment A consists of a single harvesting in the 0- to 4-ft layer on Julian day 200; treatment B consists of a single harvest in the 0- to 4-ft layer on day 225; treatment C consists of two harvestings, the first on day 175 in the 0- to 4-ft layer, and the second on day 225 also in the 0- to 4-ft layer. For each treatment the nuisance duration was reduced a specific number of days (Table 3). If the reduction in duration of nuisance is considered the primary measure of effectiveness, then treatment C is considered the most effective and treatment A is considered the least effective.

Table 3
Effectiveness of Simulated Mechanical Control Operations

Mechanical Treatments		*Effectiveness*		
Treatment	*Day:Depth*	*Nuisance Duration, days*	*Reduced Duration*	*Cost-Effectiveness**
None	—	143	0	
A	200:4′	83	60	$8.89
B	225:4′	56	87	$6.67
C	175:4′, 225:4′	17	126	$4.75

* $\frac{\text{Treatment Cost}}{\text{Reduced Duration}}$ = $/Acre/Day.

To determine the cost-effectiveness of the treatments [illegible] model HARVEST* was used. Operational and cost [illegible] determine cost are listed in Table 4. Plant densities [illegible] were predicted using the BIOGROW model simulation (Figure [illegible] hourly rental rate of the harvesting equipment (Table 4) [illegible] demobilization cost of $2000 was applied per each [illegible] i.e. once for treatments A and B and twice for treatment C. The [illegible] (rental plus mobilization demobilization) for each treatment [illegible] the number of acres harvested (45.9 acres) to give a total per acre cost. [illegible] a measure of cost-effectiveness, the calculated cost was then divided by the reduction in the duration of nuisance. This resulted in a cost for each day that the treatment alleviated the nuisance situation (Table 3). The three treatments were then compared; the double harvesting treatment (treatment C) was considered the most cost-effective and treatment A was considered least cost-effective. The cost-effectiveness difference between best and worst treatments is almost a factor of 2.

The above example for determining the cost-effectiveness of treatments provides one with a means for objectively determining the most cost-effective type of treatment to apply for this particular aquatic plant infestation.

Table 4
Harvesting Conditions Simulated with HARVEST

Mechanical harvesting system:
System: large conventional harvester with one transport unit*
System rental rate = $200/hr
Harvesting site information:
Size = 2000 ft × 1000 ft (45.9 acres)
Distance to shore takeout point = 1040 ft
Overland transport information:
Distance to upland disposal site = 1300 ft
Truck used: one 8-cu-yd dump truck

* See paper by Tommy Hutto, page 36 for a description of this system

TYPES OF DATA NEEDED

In order to determine treatment effectiveness, it is first necessary to determine the various types of data that are required by each of the various treatment methodologies. Since the types of water body use problems created by plant infestations are highly variable, control objectives would in turn be variable and would translate into different specific definitions of what constitutes effectiveness. Thus, any data base obtained to quantify effectiveness must contain data sufficiently comprehensive to gauge plant response against any type of treatment goal. Some of the descriptive statistics on plant populations which the data base might be used to estimate would include:

- Aerial coverage of floating or topped submersed plant growth

* For more information of HARVEST see pp 36-42 herein or articles by Hutto (1981, 1982).

- Total standing crop
- Standing crop within the top layer of the water column

To estimate such descriptive characteristics as these, the data base must at a minimum contain quantitative data on the three-dimensional distribution of plant biomass within the water body.

Obtaining a reliable estimate of the three-dimensional distribution of biomass is not an easy task given the extreme patchiness of most aquatic plant populations and the complexity of the sampling environment. Sampling techniques and tools routinely used to assess and quantify plant populations are listed in Table 5. Each technique by itself describes some particular characteristic of the plant population. Most of these do not provide all the data needed for gauging the effectiveness of a treatment. The only techniques which could provide the full complement of data needed (diver sampling and sampling with the WES biomass sampler) are very time-consuming and labor-intensive. In order to provide adequate data bases to measure effectiveness, an improved technique or techniques are needed to quickly obtain three-dimensional, high spatial resolution plant biomass distribution data.

Table 5
Data Collection Methods Available

Method	*Type of Data*
Visual inspection (subjective)	Percent coverage
Aerial photointerpretation (objective)	Percent coverage
Biomass samplers	Mean standing crop by layer
Fathometer	Plant height
Diver inspection/sampling	Various types

PLANS FOR FY 84

During this current fiscal year quantitative data will be collected at selected aquatic plant control plant sites in order to further develop and evaluate the concept of measuring and predicting effectiveness as described in this paper. As part of this effort several new semi-automated techniques for quickly generating high spatial resolution plant density data will be tested.

REFERENCES

Barko, J. W., et al. 1980. "Growth and Metabolism of Three Introduced Submersed Plant Species in Relation to the Influences of Temperature and Light," Technical Report A-80-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hutto, T. D. 1981. "Prediction of Equipment Performance for Optimal Mechanical Harvesting of Submerged Aquatic Plants," *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review*, Miscellaneous Paper A-81-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 197-213.

Hutto, T. D. 1982. "Simulation Modeling of Mechanical Control Systems," *Proceedings, 16th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review*, Miscellaneous Paper A-82-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 33-50.

Miller, A. 1981. "Prediction of Hydrilla Growth and Biomass for Mechanical Harvesting Operations," *Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review*, Miscellaneous Paper A-82-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 224-239.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

An Overview, Including Summary of Large-Scale Operations Management Test (LSOMT) with Insects and Pathogens in Louisiana

by
D. R. Sanders, Sr.*

OVERVIEW OF BIOLOGICAL CONTROL TECHNOLOGY RESEARCH

Direct-allotted research for FY 1983

The FY 1983 direct-allotted biological control research was apportioned among six work units, one of which was completed. These included:

a. ***Insects and pathogens for control of waterhyacinth.*** These two work units consisted primarily of follow-up research on the effects of insects and pathogens on waterhyacinth in Louisiana as a continuation of the Large-Scale Operations Management Test. All field sampling was completed and most of the data have been analyzed.

b. ***Insects for control of hydrilla.*** Overseas searches in Asia and Australia for candidate biocontrol agents were completed by the U.S. Department of Agriculture Aquatic Plant Management Laboratory, Fort Lauderdale, Fla.

c. ***Pathogens for control of hydrilla.*** Seven candidate microorganisms previously found to produce lytic enzymes were evaluated in test tube and aquarium assays to determine their effects on hydrilla.

d. ***Pathogens for control of Eurasian watermilfoil.*** Small-scale evaluation of a lytic-enzyme-producing fungus, *Mycoleptodiscus terrestris*, continued at the University of Massachusetts. Studies were also conducted to determine the mechanism of pathogenicity.

e. ***Insects for control of alligatorweed.*** A survey of alligatorweed and associated insect biocontrol agents in the southeastern United States was completed. This survey represented the status of both the plant and insect populations 10 years after the last survey conducted by the U. S. Department of Agriculture. This work unit was completed.

Support Projects for FY 1983

Two projects were undertaken in support of Corps Districts:

a. ***Biocontrol of waterhyacinth and alligatorweed in southeastern Texas.*** This project, with funds provided by the Galveston District, involved the release and establishment of all available insect biocontrol agents on waterhyacinth and alligatorweed. Both species of waterhyacinth weevils and the waterhyacinth moth were released at additional sites in Texas, and the alligatorweed thrips and the alligatorweed flea beetle were released at selected sites. Population development of the chevroned waterhyacinth weevil at Wallisville Reservoir was monitored.

---

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

b. ***Biocontrol of waterhyacinth in the San Joaquin-Sacramento River Delta in California.*** All three insect biocontrol agents were released on waterhyacinth in the San Joaquin-Sacramento River Delta. Funding for the project was provided by the State of California through the Sacramento District. Population development and dispersal of the biocontrol agents were monitored.

Direct-allotted research for FY 1984

The FY 1984 direct-allotted biological control research will be apportioned among five work units, as follows:

a. ***Insects and pathogens for control of waterhyacinth.*** For these two work units, the final reports on the Large Scale Operations Management Test in Louisiana will be published. An instruction report will be prepared to provide field guidance for the use of insects and pathogens to manage waterhyacinth. These work units will be completed.

b. ***Insects for control of hydrilla.*** The most promising group of candidate insect biocontrol agents found in the overseas searches will be selected, and host specificity and efficacy studies will be initiated in the country of origin. Such studies are necessary to obtain information in support of petitions to introduce promising species into quarantine in the United States.

c. ***Pathogens for control of hydrilla.*** Additional aquarium-level evaluation of lytic-enzyme-producing microorganisms will be conducted, and the most promising candidates will be selected for larger scale evaluation.

d. ***Pathogens for control of Eurasian watermilfoil.*** Scale-up studies of *Mycoleptodiscus terrestris* will be conducted and field evaluation will be initiated. A domestic survey will be initiated for pathogens of Eurasian watermilfoil.

Support projects for FY 1984

Support projects in Texas and California will continue. Emphasis will be placed on establishment of all available biocontrol agents and redistribution of insects to additional areas.

Future research efforts being considered

Because conventional approaches to the development of insect and pathogen biocontrol agents have not yet resulted in effective tools for the management of hydrilla and Eurasian watermilfoil, other approaches are being considered. In addition, other studies are being considered for enhancing the effectiveness of currently available biocontrol agents for the management of waterhyacinth. Future research efforts being considered include:

a. Development of simulation models for use in planning the management of waterhyacinth with biocontrol agents.

b. Biological engineering of microorganisms for control of hydrilla and Eurasian watermilfoil.

c. Feasibility of using cyanobacteria (blue-green algae) for control of hydrilla and Eurasian watermilfoil.

d. Feasibility of using nematodes for the control of hydrilla.

e. Investigation of the role of endemic microflora in unseasonal declines of hydrilla populations.

SUMMARY OF LSOMT WITH INSECTS AND PLANT PATHOGENS FOR CONTROL OF WATERHYACINTH IN LOUISIANA

Purpose

The purpose of the LSOMT was to determine the effects of biocontrol agents, when used at operational levels alone and in various combinations, on waterhyacinth in Louisiana.

Biocontrol agents

Three biocontrol agents were included in the LSOMT:

- *Neochetina eichhorniae* — the mottled waterhyacinth weevil
- *Sameodes albiguttalis* — the Argentine waterhyacinth moth
- *Cercospora rodmanii* — the waterhyacinth leaf-spot fungus

Findings

Waterhyacinth population. The waterhyacinth population in Louisiana during 1974-1978 averaged approximately 1,200,000 acres* (Figure 1). After a slight reduction in 1979 to approximately 850,000 acres, the waterhyacinth population sharply decreased in 1980 to 305,000 acres. Since 1980, the waterhyacinth population has slowly increased to an estimated 650,000 acres in 1983, which is still only about 50 percent of the 1974-1978 average.

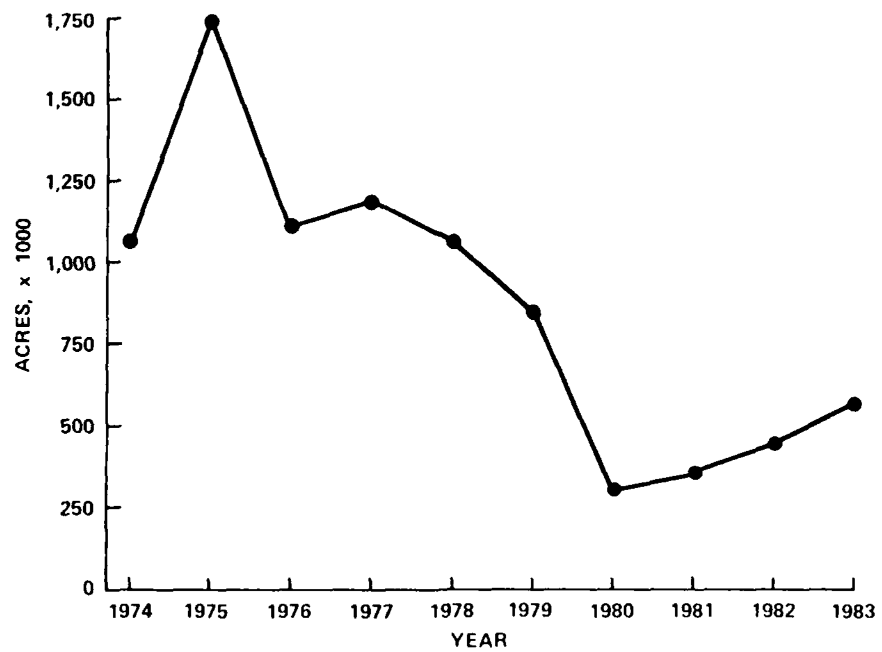


Figure 1. Waterhyacinth population in Louisiana, 1974-1983

---

* Estimated acreages furnished by the Louisiana Department of Wildlife and Fisheries.

The significant decline in the waterhyacinth population in 1980 has been attributed to three principal factors:

a. Increased efficiency of herbicide spray programs of the New Orleans District and the Louisiana Department of Wildlife and Fisheries. For example, the use of helicopters has enabled more rapid and less costly treatment of many backwater areas that previously were inaccessible.

b. A significant drought during 1980 that resulted in dewatering of many backwater areas where waterhyacinths proliferate.

c. Effects produced by expanding populations of insect biocontrol agents, principally *Neochetina eichhorniae*.

Following the drought of 1980, it had been expected that the resilient waterhyacinth population would quickly expand in 1981 to near predrought levels; however, this did not occur. In fact, no significant increase in the waterhyacinth population occurred in 1981. Clearly, other factors were limiting the waterhyacinth population.

Neochetina eichhorniae. Data collected from several study sites in southern Louisiana strongly implicated *N. eichhorniae* as a major factor, probably the principal factor, in the decline of waterhyacinth in Louisiana in 1980 and its failure to rebound in 1981. In 1980, the waterhyacinth population at one study site decreased from 92.5 percent cover in April to 13.5 percent cover in September. Plant density decreased from 116 plants/m^2 to 46 plants/m^2. The population of *N. eichhorniae* adults and larvae at the site averaged 0.69 and 1.29 individuals per plant, respectively, in July 1980. When weighted by waterhyacinth biomass and plant height, values exceeded 1.25 individuals per kilogram of plant tissue in July 1980, which was similar to values present in May. Similar, but less dramatic, decreases in waterhyacinth populations occurred at all other study sites, none of which were dewatered during the 1980 drought. Decreases in biomass ranged from 22 percent to 37 percent in October 1981 as compared to October 1980. Moderate to dense populations of *N. eichhorniae* were present on all of these sites. Sustained population densities of *N. eichhorniae* exceeding 1.0 individuals per kilogram of plant tissue appear to be sufficient to significantly impact waterhyacinth populations. The key appears to be a dense weevil population on the small waterhyacinth plants in early spring, followed by maintenance of, or increases in, population densities as the growing season progresses.

Neochetina eichhorniae populations became sufficiently dense in 1980 that a swarming phenomenon was observed in some areas. The weevils became a temporary nuisance in these areas, especially where mercury vapor lights were in use. *Neochetina eichhorniae* appears to be especially attracted to these lights. Such swarming was not observed in 1981 or 1982, but significant swarming occurred in August and September of 1983. Hopefully, this is a signal that the weevil population has increased to a sufficient level to produce a decline in the waterhyacinth population in 1984.

Neochetina eichhorniae produces the following impacts on individual waterhyacinth plants:

a. ***Adults.*** Adult weevils remove the upper leaf epidermis and often girdle the petiole at its junction with the leaf blade, which results in reduction of

available photosynthetic leaf surface, desiccation of leaf tissues, and disruption of normal gas exchange and transpiration.

b. ***Larvae.*** Larval tunneling destroys internal petiolar tissues; disrupts normal translocation of water, nutrients, and photosynthate; and damages rhizome structure. This also leads to accelerated necrosis of damaged tissues. The combined impacts produced by *N. eichhorniae* adults and larvae reduce the total photosynthate produced by individual plants and also reduces the amount of stored photosynthate. The net result over time is a decrease in biomass and severely stressed plants. When dense populations of weevils persist for long periods, the plants become progressively smaller and more severely stressed until they ultimately are unable to survive.

Cerospora rodmanii. Although the large-scale application of *C. rodmanii* resulted in establishment and overwintering of the fungus at one study site, its impacts on waterhyacinth were much less than had been expected. It appeared to stress waterhyacinth during the year after application, but did not occur at significant population levels after 2 years and did not spread to adjacent waterhyacinth populations. The fungus failed to become established at a second study site, apparently because the strain used in production of the applied formulation lacked sufficient virulence to infect the plants.

Sameodes albiguttalis. *Sameodes albiguttalis* was released at two locations in 1979, and a population became established near one of the sites. Since then, the moth has dispersed to an area that encompasses approximately 75 percent of the waterhyacinth population in Louisiana (Figure 2). Due apparently to the relatively harsh winters that result in significant mortality of the overwintering populations, abundant populations of *S. albiguttalis* occur in late summer and fall. Nevertheless, sufficient populations have developed in some areas to significantly impact waterhyacinth populations, and *S. albiguttalis* may ultimately become an important tool in the management of waterhyacinth.

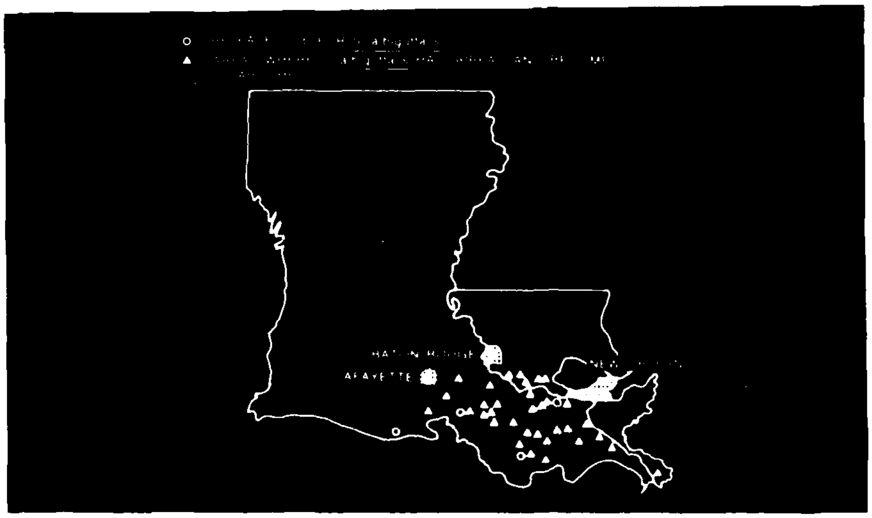


Figure 2. Populations of *Sameodes albiguttalis* established in Louisiana by October 1983

Conclusions

Studies conducted as part of the LSOMT revealed that insect biocontrol agents, particularly *Neochetina eichhorniae*, are effective tools for the management of waterhyacinth, and that they are capable of effecting a reduction in the size of the plant populations. The result is significant, long-term, economical aquatic plant management. However, it is unlikely that the biocontrol agents will effectively eliminate the need for herbicidal control of waterhyacinth in Louisiana due to the rapid regrowth potential of waterhyacinth, the intimate relationship between the insect agents and waterhyacinth that results in the abundance of waterhyacinth acting as a controlling influence on the size of the insect populations, and the continuing need to rapidly eliminate nuisance populations of waterhyacinths from high-use areas.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Biological Control Activities in Texas and California

by
A. F. Cofrancesco, Jr.*

TEXAS STUDY

Introduction

Alligatorweed and waterhyacinth are two of the most troublesome aquatic plants in the United States. In research sponsored by the Corps of Engineers' Aquatic Plant Control Research Program (APCRP) three insects were identified for alligatorweed control, the alligatorweed flea beetle (*Agasicles hygrophila* Selman and Vogt), the alligatorweed stem borer (*Vogtia malloi* Pastrana), and the alligatorweed thrips (*Amynothrips andersoni* O'Neill). Three insect species have also been identified by APCRP as biocontrol agents of waterhyacinth. These insects include the mottled waterhyacinth weevil (*Neochetina eichhorniae* Warner), the chevroned waterhyacinth weevil (*Neochetina bruchi* Hustache), and the Argentine waterhyacinth moth (*Sameodes albiguttalis* Warren).

Biological control agents have not been extensively employed in Texas in the past. *Agasicles hygrophila* and *Amynothrips andersoni* were first released on alligatorweed in the late 1960s but their impact appeared limited; *Vogtia malloi* was never released in Texas. Waterhyacinth biocontrol insects were never established in Texas although a release of *N. bruchi* was attempted in the mid 1970s.

Discussion of aquatic weed problems between the U.S. Army Engineer District, Galveston, and the Waterways Experiment Station (WES) resulted in a proposal being submitted by WES to assist in controlling aquatic weed problems for the Galveston District. A framework for introduction and evaluation of all insect species was established. Previously introduced insect species on alligatorweed would also be investigated, with special emphasis placed on the determination of environmental factors that may be limiting the effectiveness of these insects in controlling alligatorweed.

Purpose and objectives

A multiyear study was proposed to the Galveston District in 1979 which would (1) evaluate and make recommendations about the alligatorweed problems and (2) make initial establishments and monitor the impact of the biocontrol agents on waterhyacinth.

Study area

Five study sites (Figure 1) were selected in Texas and these included some of the major problem areas for alligatorweed and waterhyacinth: Wallisville Reservoir, J.

---

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

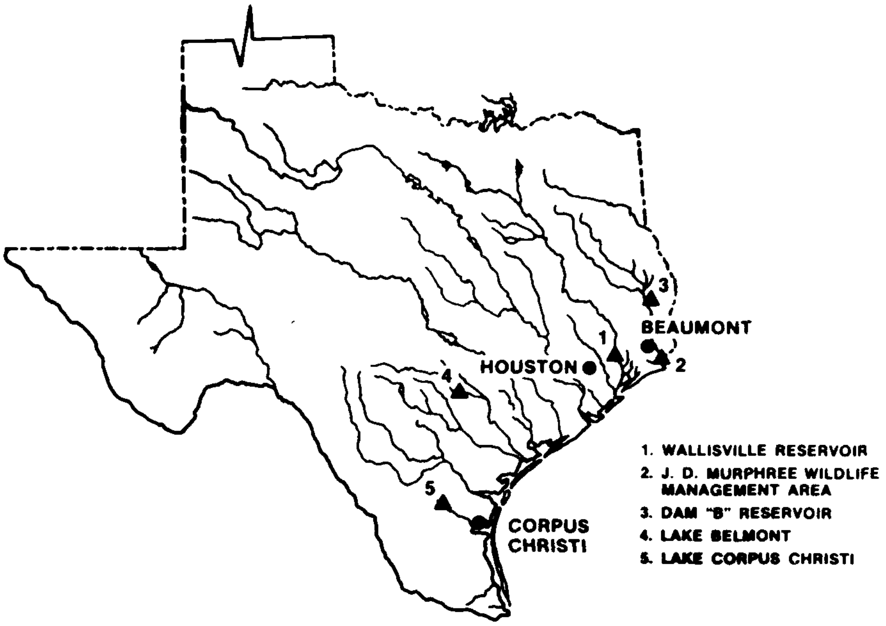


Figure 1. Texas site locations

D. Murphree Wildlife Management Area, Dam "B" Reservoir, Lake Belmont, and Lake Corpus Christi. From 1980 to 1982, only the first three sites located in eastern Texas were utilized, and both waterhyacinth and alligatorweed were monitored. The last two sites have only waterhyacinth infestations and were not utilized until 1983.

Alligatorweed problem

Alligatorweed in Texas is a problem in both the terrestrial and the aquatic form. *Agasicles hygrophila* was released in 1967 and established itself on the alligatorweed. This insect, which prefers the aquatic form of alligatorweed, initially appeared to be controlling alligatorweed. After a short period of time, however, the insect population was noticeably reduced. The typical type of *Agasicles* control that was being observed in Florida and South Carolina was not being produced in Texas.

Of the two other biocontrol insects approved for release in control alligatorweed, only *A. andersoni* was released in Texas. The first release efforts in Texas of the alligatorweed thrips were conducted in 1968. This insect, unlike the flea beetle, prefers the terrestrial form of alligatorweed. Unfortunately, establishment of this species in Texas was never reported. The alligatorweed stem borer was the last insect to be brought into the United States for alligatorweed control. Records indicate that this insect, which also prefers the aquatic form of alligatorweed, was never released in Texas. Stem borer releases were limited to five states (Florida, Georgia, North Carolina, South Carolina, and Alabama).

Initially in this study we wanted to determine the status of both alligatorweed and the biocontrol insects in Texas. Examination of the sites through 1981 indicated the following points:

a. Alligatorweed was subjected to extreme fluctuations in water level over relatively short periods of time and these fluctuations were not necessarily associated with seasonal change.

b. Numerous terrestrial mats of alligatorweed were observed but their infiltration into the surrounding aquatic habitat seemed to be limited by the biocontrol insects.

c. The *A. hygrophila* population was widely distributed in Texas late in the growing season but the insect numbers were usually low.

d. *Amynothrips andersoni* was not present at any of the Texas study sites.

e. *Vogtia malloi* was present in the study sites and had a significant seasonal impact.

Based on the results of the initial evaluation period, it was determined that re-releases of both *A. hygrophila* and *A. andersoni* would be beneficial in reducing the alligatorweed population. In July 1983 releases of both insect species were made at three locations (J. D. Murphree Wildlife Refuge, Wallisville Reservoir, and Dam B). Two weeks after the releases, hurricane Alecia devastated the Texas coast and impacted all of the release sites. Additional releases will be made in the spring of FY 1984.

Waterhyacinth problem

At the beginning of this study none of the biocontrol agents impacting waterhyacinth were present in Texas. The initial releases of all three biocontrol insects (*Neochetina bruchi*, *Neochetina eichhorniae*, and *Sameodes albiguttalis*) occurred during 1980 and 1981.

Neochetina bruchi was first released in May 1980 at the Wallisville Reservoir. After a slow initial buildup, the *N. bruchi* population increased dramatically. Waterhyacinth plants had heavy adult weevil feeding scars that girdled the petioles. The impact that the insects have produced in the 3 years since their release is a 90 percent reduction in waterhyacinth coverage of the test site (Figure 2).

Neochetina eichhorniae was released at J. D. Murphree Wildlife Refuge in April 1981. Just prior to the release, adult *N. eichhorniae* were found at the refuge. These adults probably migrated into this area from Louisiana. *Neochetina eichhorniae* was still released, and together with the immigrating individuals, have established themselves in Texas from J. D. Murphree Wildlife Refuge north to Lake Sam Rayburn.

Once weevil populations were established in eastern Texas, releases were made at Lake Belmont and Lake Corpus Christi. These releases were started in July 1983 when both *N. bruchi* and *N. eichhorniae* were released at Lake Belmont and *N. bruchi* was released at Lake Corpus Christi. Site examination in October 1983 indicated that the insects were becoming established. Another site examination is scheduled for spring of FY 1984 to determine if the weevils were able to overwinter at these new sites.

The waterhyacinth moth, *Sameodes albiguttalis*, was also introduced into Texas. Its first release was in April 1981 at J. D. Murphree Wildlife Refuge, but no apparent population was established. A second release at J. D. Murphree Wildlife

a. **Before weevils were released (1980)**

b. **After weevil impact (1983)**

Figure 2. Impact of *N. bruchi*

Refuge was conducted in July of 1983, and during the October 1983 site visit, larvae were collected 1 mile from the release area.

CALIFORNIA STUDY

Introduction

The California Delta is located at the confluence of the Sacramento and San Joaquin Rivers. Although this is a relatively small infestation in comparison to problem areas in the southeastern United States, the economic impact could be severe.

Purpose

The purpose of this study is to achieve rapid control of the waterhyacinth infestation in the California Delta by applying biocontrol technology in conjunction with chemical and mechanical methods.

Phases of the study

The phases of this study are as follows:

a. Permission was obtained to release three biocontrol agents (*Neochetina bruchi, Neochetina eichhorniae,* and *Sameodes albiguttalis*) on waterhyacinth in California.

b. Four strategically located release sites were selected. Each site would receive a predetermined combination of biocontrol agents.

c. Insects were collected and shipped to the U.S. Department of Agriculture (USDA) quarantine facility in Albany, Calif., for species verification and parasite/pathogen examination.

d. Weevils (*N. bruchi* and *N. eichhorniae*) were released directly to the sites after being cleared from quarantine. The moth (*S. albiguttalis*) was established in a greenhouse at a state facility. Releases of *S. albiguttalis* were then made from the existing greenhouse population.

e. Release sites are being monitored to record the population buildup of the insects and the condition of the waterhyacinth plants at each site. Monitoring is also being conducted to determine the dispersal of the insects into adjacent waterhyacinth infestations. Table 1 indicates the insect releases which have been conducted. Additional releases will be made in 1984. Currently we are continuing to monitor the release sites and dispersal sites.

f. Recommendations will be made after 3 years as to how the insect population should be managed for the existing waterhyacinth population.

Table 1
Summary of Biocontrol Agent Releases in the California Delta by Site

Release Site	*Agent*	*First Release*	*Total To Date*
Galli	*Neochetina bruchi*	July 1982	1150
	Sameodes albiguttalis	August 1983	200
Trapper Slough	*Neochetina bruchi*	October 1982	850
	Neochetina eichhorniae	August 1983	700
	Sameodes albiguttalis	August 1983	1354
Whites Slough	*Neochetina eichhorniae*	April 1983	1600
Veale Tract	*Neochetina bruchi*	October 1983	500
	Neochetina eichhorniae	October 1983	1500

Discussion

Neochetina bruchi, which was released in October 1982, is the only insect that was released before the 1982-83 winter. Both *N. eichhorniae* and *S. albiguttalis* were released in the spring of 1983 and they will be subjected to their first winter this year (1983-84). The survival and population buildup of *N. bruchi* generally indicates that the other two insect species will have no problem overwintering.

Currently we are monitoring the release sites and the dispersal of the insect populations. At the release sites we are getting a moderate increase in the population but no dispersal of the insects has been detected.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Microbiological Control of Hydrilla with Lytic-Enzyme-Producing Microorganisms

by
Judith C. Pennington*

BACKGROUND

Hydrilla is a submersed aquatic plant that interfers with drainage, irrigation, fishing, swimming, and boating. It was first discovered in this country in the late 1950s. It is an exotic plant from Asia or Africa. Although it has been here for about 25 years, its major spread has occurred in the last 15 years. It now encompasses 100 to 150 thousand acres in 11 states including the Tennessee Valley Authority (TVA) system.

Hydrilla has a competitive advantage over native submersed plants because:

a. It has no known natural enemies in this country.

b. It can reproduce by a variety of vegetative methods. It is also capable of sexual reproduction by seeds, but staminate flowers are rare and reproduction from seeds has not yet become a problem.

c. It can tolerate a wide range of water conditions (e.g. eutrophic to oligotrophic).

d. It requires much less sunlight than native species.

Overseas surveys for insect biocontrol agents are in progress and some domestic searches for microbiological control agents, primarily in Florida, have been conducted. However, no effective agents are currently available.

APPROACH

The approach used in this study consisted of isolating bacteria and fungi from the ecosphere of hydrilla and screening them for production of enzymes that can lyse specific plant components. These microorganisms were successively subcultured on restrictive media to enhance their enzyme production and then reintroduced to hydrilla in the hope that their more powerful enzyme systems would enable them to attack plant tissues. The rationale for this approach was prompted by promising work done on Eurasian watermilfoil by Dr. Haim Gunner, University of Massachusetts (Amherst).

CANDIDATE SELECTION

The first objective of the study was candidate selection. Hydrilla samples were collected from the Imperial Valley, California; Lake Conroe, Texas; Lake Theriot, Louisiana; and Lake Trafford, Florida. Plants were separated into the following

---

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

plant parts for culturing: meristematic stem tips, leaves, stems, roots, turions (when present), and tubers (when present). The plant parts were rinsed thoroughly, ground, and plated on nutrient agar and potato dextrose agar for isolation of bacteria and fungi.

Two hundred sixteen microorganisms were isolated: 139 bacterial isolates included in genera listed in Table 1, and 55 fungal isolates (Table 2). Dr. Tim

Table 1
Genera of Bacteria Associated with Hydrilla

Isolate	*Number of Isolates*	*Isolate*	*Number of Isolates*
Pseudomonas	33	*Myconostoc*	1
Pseudomonas (fluorescent)	5	*Rhodopseudomonas*	1
Acinetobacter	27	*Serratia*	1
Aeromonas	14	*Caulobacter*	1
Flavobacterium	12	*Agrobacterium*	1
Bacillus	5	*Hafnia*	1
Enterobacter	3	*Klebsiella*	1
Alcaligenes	2	*Sporocytophaga*	1
Flexibacter	2	Unidentified*	19
Erwinia	1	Lost**	8

* Isolates that could not be keyed to genera with tests performed.

** Isolates lost while holding cultures.

Table 2
Fungal Isolates

Isolate Number	*Name*	*Isolate Number*	*Name*
Cellulase Positive		**Cellulase Positive (Continued)**	
49	*Penicillium* sp.	249	*Aspergillus awomori* Nakazawa
56	*Aspergillus awomori* Nakazawa	250	*Aspergillus awomori* Nakazawa
57	*Aspergillus* sp.	**Pectinase Positive**	
59	*Cephalosporium acremonium* Corda	224	*Cladosporium cladosporioides* (Fresen.) de Vries
101	*	**Cellulase/Pectinase Negative**	
111	*Cephalosporium acremonium* Corda	20	*Aspergillus* sp.
116	* with Chlamydospores	21	*
156	*Humicola* sp. with *Trichoderma* sp.	28	*Cylindrocarpon* sp.
157	*Aspergillus luchuensis* Invi	31	*Rhizoctonia* sp. (with sclerotia, not same sp. as 237)**
161	*Humicola* sp. with *Trichoderma* sp.	32	*Rhizopus stolonifer* (Ehrenb. ex Link) Lind.
162	*Cephalosporium acremonium* Corda	45	*Cladosporium cladosporioides* (Fresen.) de Vries
170	*	159	*Aspergillus luchuensis* Inui
236	*Fusarium moniliforme* Sheldon var. *subglutinans* Wr. & Reink	163	*Aspergillus luchuensis* Inui
237	*Rhizoctonia* sp.** with *Trichoderma* sp.	164	*Aspergillus luchuensis* Inui
238	*	245	*
240	*	246	*
242	*		
244	*		

* Unidentified.

** Not previously described.

Schubert of the Florida Department of Agriculture and Consumer Services identified the fungal isolates.

All isolates were screened for cellulase and pectinase production. Pectinase production was determined by the ability of the isolates to utilize a thin layer of pectin medium overlying a mineral salts agar base. Cellulase production was determined by a cellulose-azure tube test. Basal mineral salts agar was overlaid with a thin layer of cellulose-azure. When a microorganism utilizes cellulose, it is uncoupled from the azure (a blue dye) and the azure diffuses into the clear basal medium.

One pectinase-positive bacterium (*Erwinia herbicola*) and one pectinase-positive fungus (*Cladosporium cladosporioides*) were found. Twenty cellulase-positive fungi, but no cellulase-positive bacteria, were found. Lytic enzyme production of these isolates was enhanced by successive subculturing on media in which cellulose or pectin was the sole carbon source.

TEST TUBE ASSAY

In order to fulfill the second objective of the study, a test tube assay was designed to test the pathogenicity of 22 lytic-enzyme-enhanced isolates. Hydrilla sprigs from a field population were placed in 200- x 25-mm test tubes and inoculated in seven replicates. Damage index values were defined prior to test initiation as follows:

Index	Description
1	Healthy
2	Slightly chlorotic with few or no damage spots
3	Chlorotic and/or damage involving less than 50 percent of sprig
4	Damage exceeding 50 percent of sprig
5	Dead sprig

Five of the isolates produced significantly greater damage index values than controls after only 1 week. Isolate 56 (*Aspergillus awomori*) exhibited the greatest difference from treated (potato dextrose broth) controls each week of the 6-week test period. Axillary branches that developed after test initiation were also damaged. Data for two isolates are shown in Figure 1. Damage index values of treated controls increased during the fifth and sixth weeks, possibly because nutrients stimulated the microflora originally associated with the sprigs sufficiently to enable them to cause damage.

All tubes showing significant damage were cultured to recover the introduced microorganism. The inoculated microorganism was recovered from 75 percent of the cultured tubes.

AQUARIUM ASSAY

A preliminary aquarium assay was conducted with the seven isolates producing greatest damage in the test tube assay. Greenhouse-grown hydrilla sprigs were

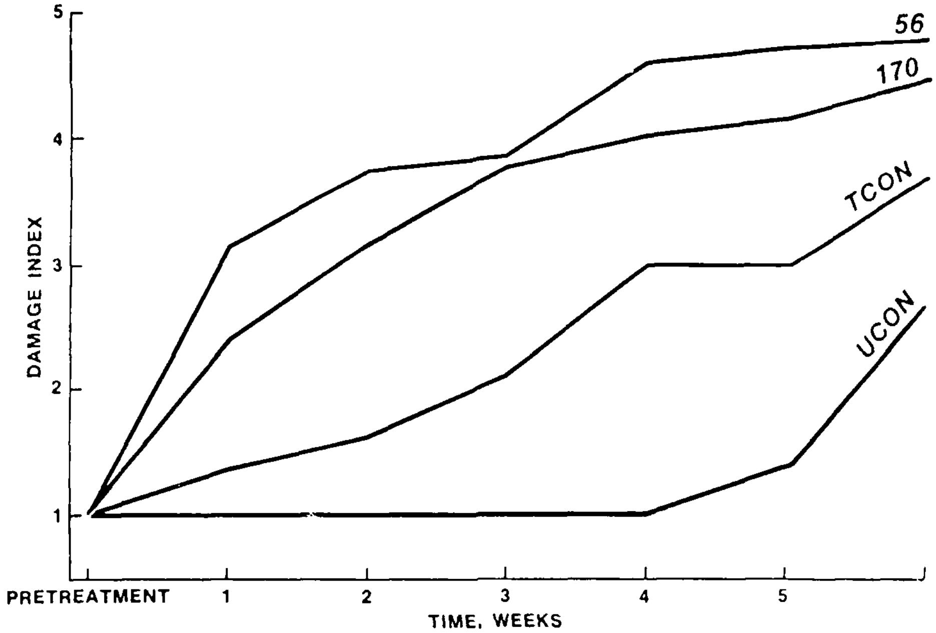


Figure 1. Damage index values for two of the seven best isolates (56 and 170) on hydrilla sprigs in test tubes through the 6-week study period. TCON represents potato dextrose broth treated controls, and UNCON represents untreated controls

rooted in a mixture of lake sediment and sand. The inoculum was prepared, filtered, and resuspended in water in order to reduce the nutrient level resulting from the production of large quantities of inoculum.

None of the treatments exhibited significant differences from controls in damage index values nor in reductions of biomass. Results of this preliminary aquarium assay suggest several questions:

a. Did higher nutrient levels in the test tube assay than in the aquarium assay contribute to the effectiveness of the isolates?

b. Did hydrilla plants obtained from a field population for use in the test tube assay differ in resistance from the greenhouse-grown hydrilla used in the aquarium assay?

c. Could the additional "processing" of the isolates necessary to produce larger quantities for the aquarium assay have exerted an influence on the inoculated microorganisms?

d. Could accumulated lytic enzymes in the inoculum have played a part in the early impacts seen in the test tube assay? (These enzymes were filtered from the inoculum used in the aquarium assay.)

e. Could aeration of the aquaria have prevented establishment of the isolates on the plants?

f. Are the isolates incapable of damaging actively growing aquarium plants?

g. Are there inoculum threshold levels below which the isolates are ineffective?

Additional test tube and aquarium assays will be conducted to answer these questions and the most promising candidates will be tested at a larger scale in tanks.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Microbiological Control of Eurasian Watermilfoil

by
Haim B. Gunner*

INTRODUCTION

Studies reported previously have shown that inoculation of *Myriophyllum spicatum* and *M. heterophyllum* with enzyme-enhanced pectinolytic or cellulolytic microorganisms originally isolated from these species significantly accelerated plant necrosis. Subsequent studies, reported below, have attempted to assess plant response to inoculation under a variety of stress conditions, to define infection thresholds, and to enlarge the scale of infection trials.

METHODS AND MATERIALS

Plant preparation

Myriophyllum spicatum and *M. heterophyllum* were harvested from Horse Pond, a component of Hampton Pond, Westfield, Massachusetts. After washing twice, the selected plant tips were rooted in a 10-gal aquarium equipped with an air bubbler and a Sylvania Gro-Lux light. When root formation was observed, two plants were transferred into each experimental jar containing approximately 800 ml of Angiosperm medium.

Bacterial counts

The counts in medium were obtained by the variable plate count technique. A sample was taken from the Angiosperm medium and plated on Nutrient agar (NA) for total count enumeration and on Pectin agar (PA) for pectinolytic bacterial counts. The counts on the plant surface were taken after the experimental plant was shaken reciprocally in 25 ml sterile distilled water 100 times. The bacterial counts of plant tissue were performed after the addition of 25 ml sterile distilled water to the above plant material and after maceration in a Waring blender maintained at maximum speed for a few seconds. Bacterial numbers were determined following 72 hr incubation at 28°C.

Bacterial cultures

The bacterial cultures used as inocula were grown in 0.25 percent Pectin medium. The cells were harvested by centrifugation and resuspended in sterile normal saline. The viable cells were counted on both NA and PA.

* University of Massachusetts, Amherst, Massachusetts. With the participation of Yuthana Lumpa-Amara and Beryl Bouchard.

Plant hormones

The plant hormones, gibberellic acid, indoleacetic acid, and α-naphthaleneacetic acid, were diluted to 1000 ppm (w/v) before final dilution to 500, 100, 50, and 5 ppm. The α-Naphthalene acetic acid was suspended in 70 percent alcohol to prevent precipitation.

Aquarium experiments

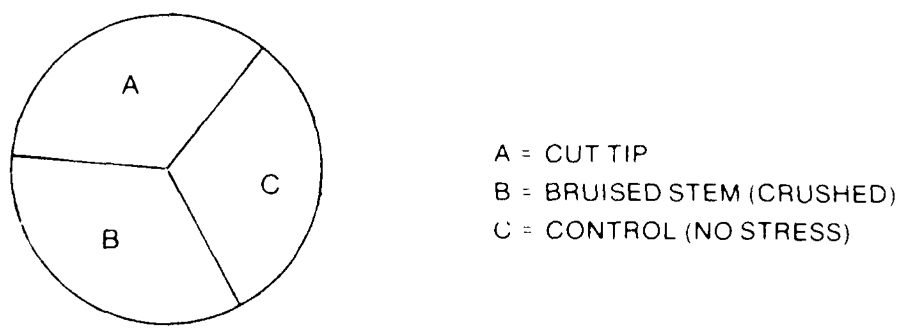
Four 10-gal aquaria were set up in a laboratory setting under 4-ft Gro-Lux lights (12 hr on: 12 hr off cycle). Fresh plant tips were placed in tanks and allowed to root for 10 days. Two tanks contained *M. heterophyllum* and two *M. spicatum*. There were 12 to 15 plants per condition and 3 conditions per tank. One tank of each species was inoculated; the other served as a control. Plants were stressed on the same day as the initial inoculation. Tanks were divided into thirds for stress treatment: A = cut tips, B = crushed stems, C = no stress. Plants were observed weekly after inoculation.

Inoculum

An aliquot of the cellulolytic fungus (CF) inoculum was dried to quantify inoculum levels. Each millilitre of inoculum represented 5.5 mg dry weight (fungus and remaining cellulose) or 275 mg dry weight/tank in the 50-ml initial inoculation. This represents a 1/135 dilution of inoculum (w/v).

Pool experiments

Six 6-ft × 15-in. swimming pools were set on the ground in a sheltered outdoor setting. Each pool contained approximately 3 in. of coarse washed sand for rooting the plants and tap water to fill the pool. The pools were allowed to settle and fresh *M. spicatum* and *M. heterophyllum* tips were placed in three pools for each species. A shade net was suspended about 3 ft above the pool area. This provided approximately 50 percent shade and at the same time adequate ventilation. Tips were allowed to root for 10 days before inoculation. The plants were mechanically stressed on the same day as the first inoculation. Pools containing stressed plants were divided into triads as noted below.



Inoculum

The first inoculation took place 10 days after plants were placed in pools (day 0). The second inoculation was 1 week after the first inoculation (day 7). A third inoculation was made with a slightly smaller amount of inoculum after 6.5 weeks (day 45)—only pools 1 and 2 were inoculated.

RESULTS

The data in Figures 1-3 represent the numbers of bacterial populations recovered from the growth medium, surface, and macerated tissue, respectively, of *M. heterophyllum* in a 3-week period beginning 3 days after plant transfer to fresh Angiosperm medium. As might be anticipated, numbers initially rose sharply in the medium, reflecting a lack of competition to populations introduced to the plant material. At about day 2, however, a sharp decline occurs both in total numbers and among the pectinolytic bacteria. This pattern is present in the counts obtained both from the plant surface and from macerated *Myriophyllum* tissue. The most acute decline appears in the recovery of communities from the plant surface suggesting that this is the locus of the inhibitory effect. The recovery in numbers would appear to imply the appearance of a second population more immune to the inhibitory mechanism and further that the pectinolytic community at least in part shares this immunity.

Figures 4-6 reflect the population changes in a similar setting, but in which there has been the addition of the pectinolytic bacterium YP-4. Counts in the Angiosperm medium (Figure 4) reflect the rapid decline of total counts, and the virtual

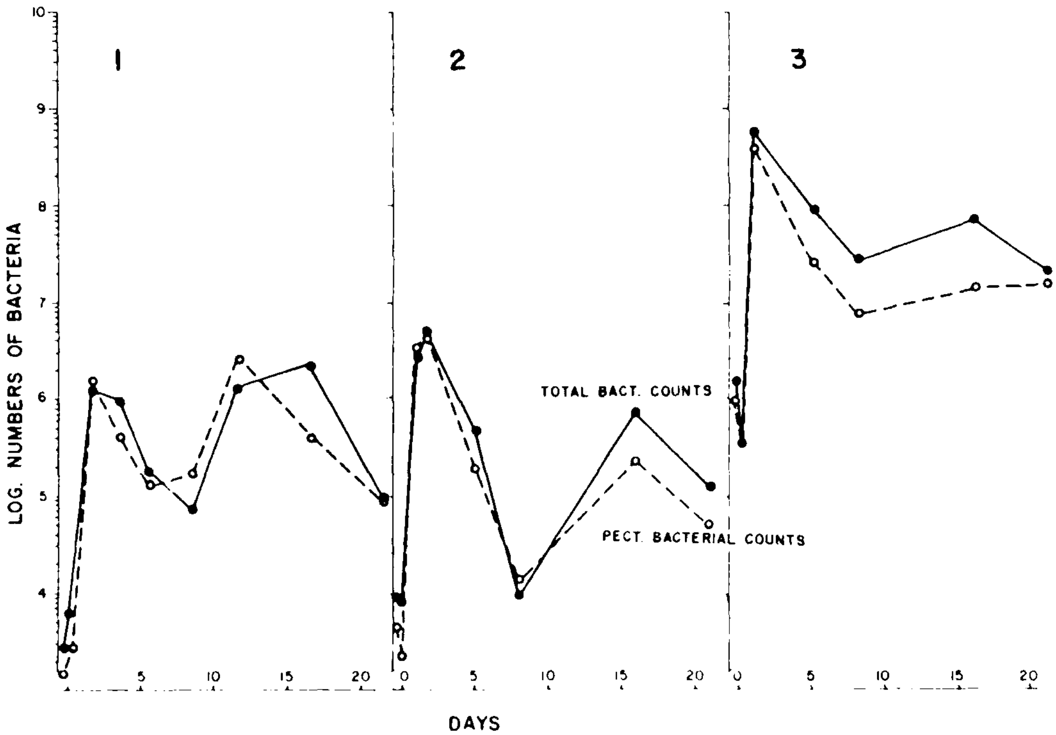


Figure 1. Bacterial populations recovered per millilitre of Angiosperm medium in the presence of *M. heterophyllum*

Figure 2. Bacterial populations recovered per gram wet weight from the surface of *M. heterophyllum*

Figure 3. Bacterial populations recovered per gram of macerated tissue of *M. heterophyllum*

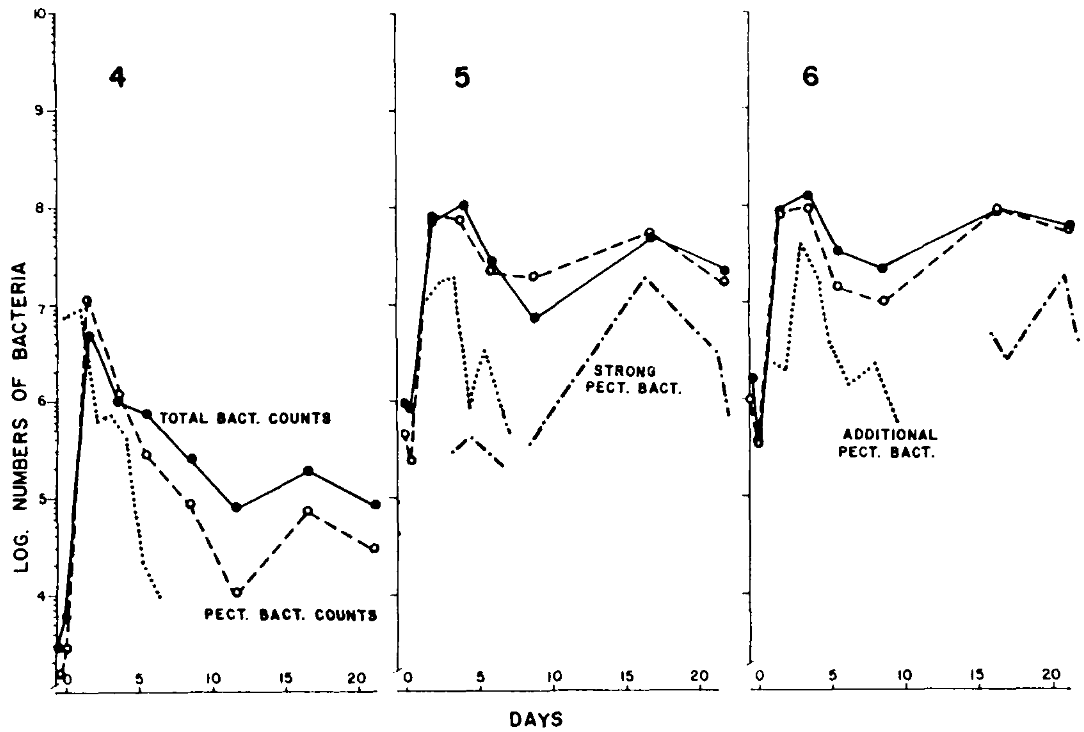


Figure 4. Effect of the addition of a selected pectinolytic bacterium YP-4 on bacterial populations recovered per millilitre of Angiosperm medium supporting *M. heterophyllum*

Figure 5. Effect of the addition of a selected pectinolytic bacterium YP-4 on bacterial populations recovered per gram wet weight from the surface of *M. heterophyllum*

Figure 6. Effect of the addition of a selected pectinolytic bacterium YP-4 on bacterial populations recovered per gram of macerated tissues of *M. heterophyllum*

elimination of the added YP-4 by day 7. Counts of populations from the plant leaf surface (Figure 5), however, reveal the emergence of a strongly pectinolytic endogenous population not present in systems uninoculated with YP-4. This could indicate that YP-4 had made sufficient pectin or pectin residues available to stimulate the emergence of the native pectinolytic populations present on the plant surface. Though these populations too are not immune to the plant defense mechanisms as witnessed by their oscillating numbers, they are ultimately capable of withstanding these effects and sustaining extensive growth. Significantly, the actively pectinolytic native populations are strongly bound to the plant surface and accordingly do not appear in the growth medium. Only in plant surface and macerated plant tissue counts are they evident and no meaningful increase in numbers was obtained from whole tissue counts.

In the presence of the auxin analog, α-naphthaleneacetic acid, added as a plant stress agent (Figures 7-9), no essential change on population distribution occurs, except in the growth medium. In this instance it may reflect an interaction between the auxin and selected microbial populations. The increase in total numbers may

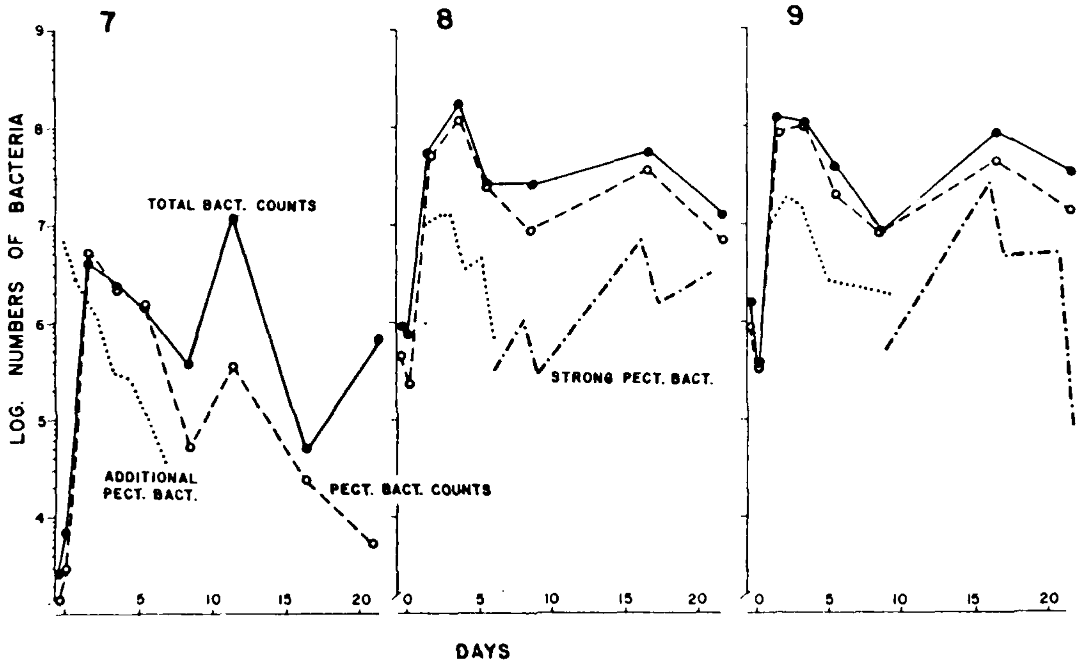


Figure 7. Effect of the addition of a selected pectinolytic bacterium YP-4 on bacterial populations recovered per millilitre of angiosperm medium supporting *M. heterophyllum* to which α - naphthaleneacetic acid has been added

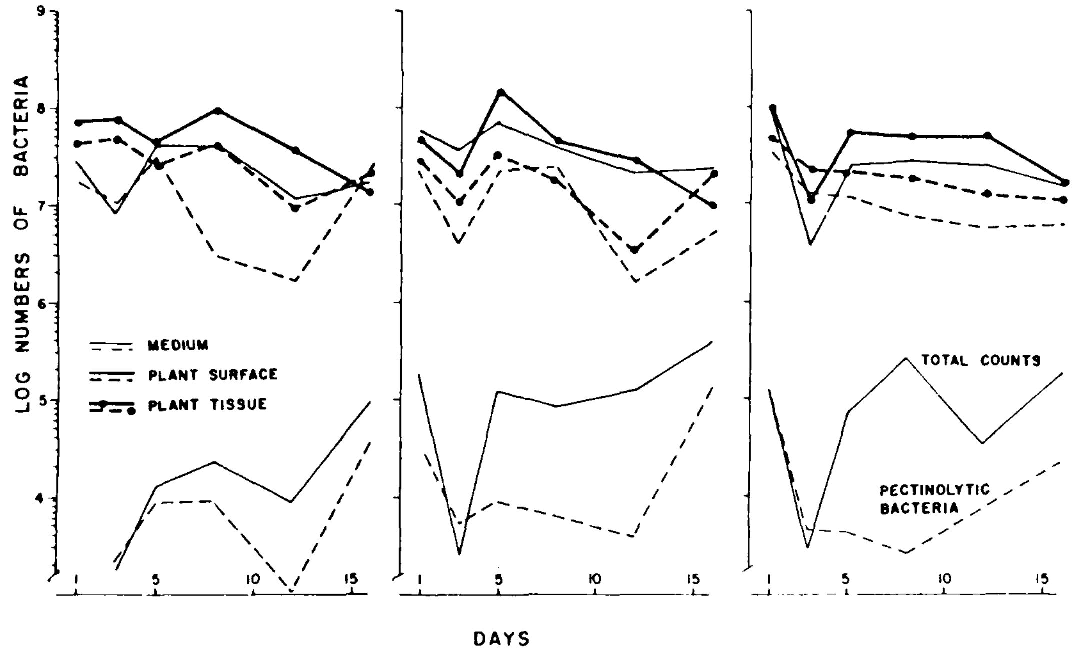
Figure 8. Effect of the addition of a selected pectinolytic bacterium YP-4 on bacterial populations recovered per gram wet weight from the surface of *M. heterophyllum* grown in Angiosperm medium in the presence of α - naphthaleneacetic acid

Figure 9. Effect of the addition of a selected pectinolytic bacterium YP-4 on bacterial populations recovered per gram of macerated tissues of *M. heterophyllum* grown in Angiosperm medium in the presence of α - naphthaleneacetic acid

reflect a selective population response rather than an undifferentiated general increase in numbers. The pectinolytic population emergence seemed in any event unperturbed by the presence of the analog and the general population maxima were consistent with treatments in which it was absent. No significant effects were observed with any of the other plant hormones or growth-influencing agents tested.

The data in Figure 10 provide an indication of the threshold infection levels at which the pectinolytic bacterium MH2 appears able to vitiate the plant's defensive response and to impose broad population changes. As the inoculum level approaches 9×10^9 CFU/ml there is a progressive redistribution of the entire plant surface population reflecting the pressure exercised by the successful recolonization of an isolate originally derived from the *Myriophyllum* ecosystem.

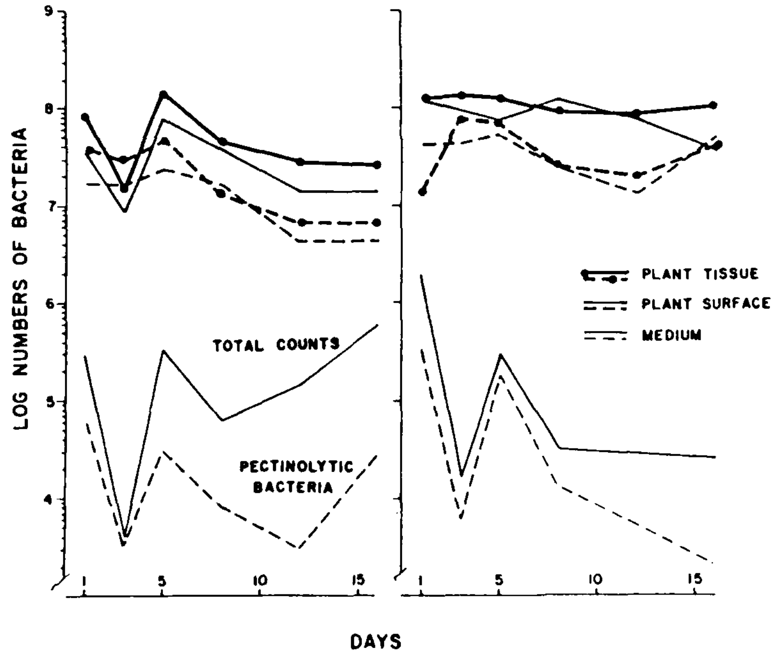
When the effectiveness of inocula was tested on injured and uninjured plants in both aquaria and pools, results were consistent with the foregoing. As may be seen from the aquarium data (Figures 11a-d, Table 1), and results in the larger pools (Table 1, Figure 12), the injured plants remained virtually unaffected by the inoculum while the uninjured plants succumbed readily.



a. Control, uninoculated

b. After inoculation with 1.5 × 10⁸ CFU/ml

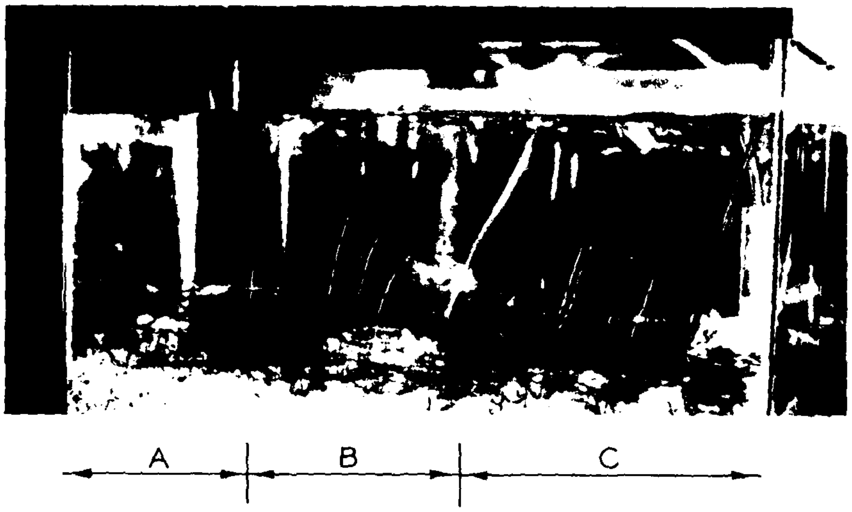
c. After inoculation with 3 × 10⁹ CFU/ml



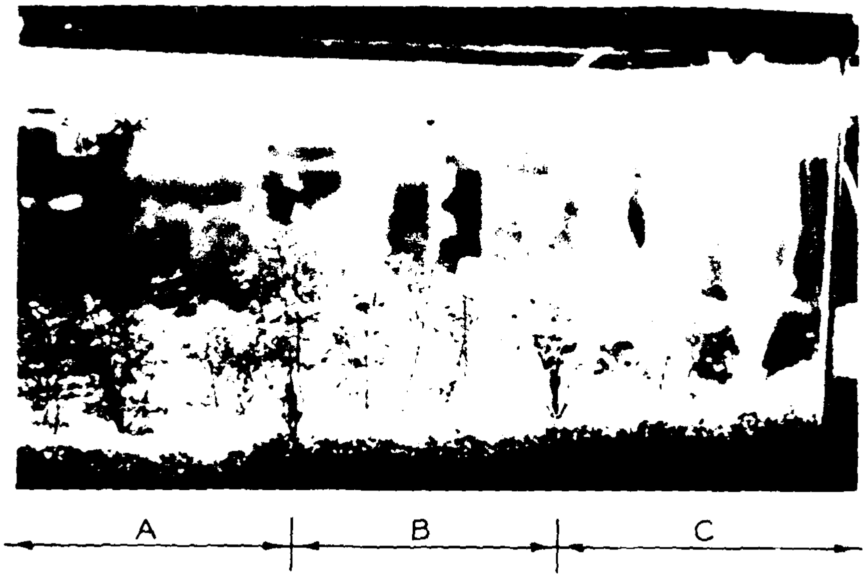
d. After inoculation with 6.9 × 10^9 CFU/ml

e. After inoculation with 9 × 10^9 CFU/ml

Figure 10. Establishment of an inoculum threshold for the pectinolytic bacterium MH2 on *M. heterophyllum*. Numbers of bacteria present after simulated inoculation

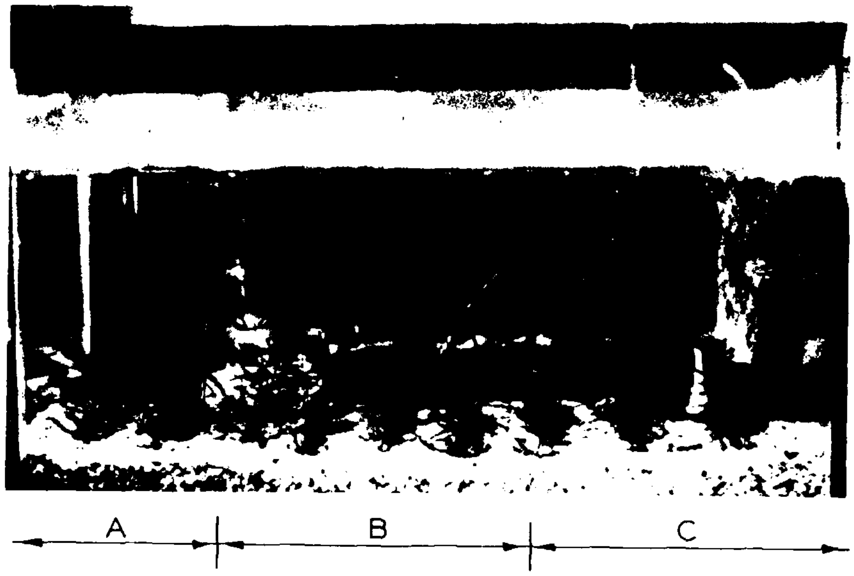


a. Control, day 0

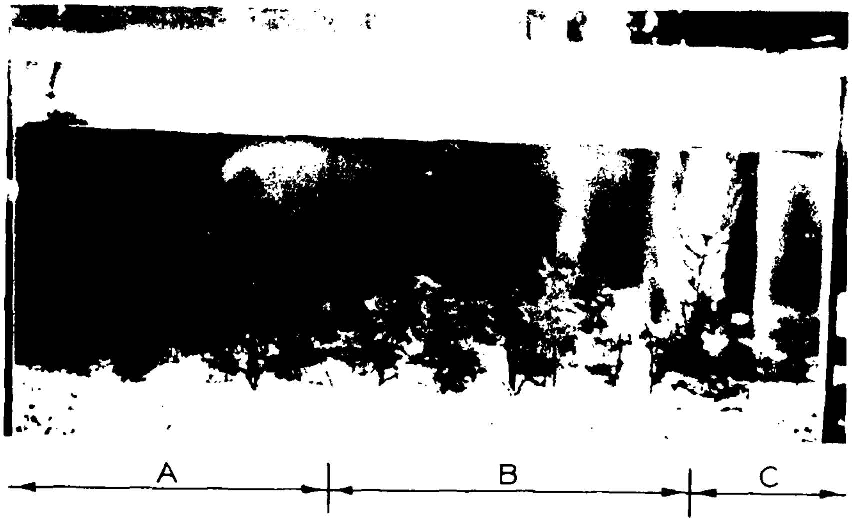


b. Cf inoculum, day 0

Figure 11. Mortality of *Myriophyllum spicatum* treated with fungal isolate Cf (Continued)



c. Control, day 14



d. Cf inoculum, day 14

Figure 11. (Concluded)

Table 1

Mortality of *Myriophyllum spicatum* Treated with Fungal Isolate Cf

Treatment	*Percent Mortality at 21 days*	
	Inoculated	*Uninoculated*
Studies in Laboratory Aquaria		
Plant cut	33	0
Plant bruised	27	0
Plant uninjured	77	0
Outdoor Pool Study		
Plant cut	45*	30
Plant bruised	65*	10
Plant uninjured	75*	15

* Student's t value = 4.04, 99 percent significance level for this group.

Figure 12. Pools for outdoor study of *Mycrophyllum* sp. treated with fungal isolate Cf

DISCUSSION

The above results seemingly appear counter-inituitive in that it might be assumed that the breach of plant integrity ought to make it more vulnerable to infection. However, recent work by Planas et al.* shows that *M. spicatum* is capable of releasing a wide array of phenolic compounds through extracellular secretion and plant tissue decomposition which exercise a significant selective effect on surrounding populations. Our previous results obtained with damaged nongrowing plant material did decompose more readily than undamaged. However, growing undamaged plants capable of phenolic excretion reversed this pattern and more effectively resisted infection than did damaged plants.

WORK REMAINING

Future studies will include the following:

a. It is proposed that emphasis be given to refining inoculation strategies and the establishment of infection thresholds for two selected organisms: the cellulolytic fungus *Mycoleptodiscus terrestris*, and the pectinolytic bacterium YP-4.

b. Studies will be conducted on *M. spicatum* phenolic excretions and attempts made to isolate resistant variants to these compounds among the *M. terrestris* and YP-4 isolates.

c. Final scaling up for prefield applications of the effective inocula will be conducted.

---

* Planas, D., et al, 1981. "Ecological Significance of Phenolic Compounds of *Myriophyllum spicatum*," *Verh. Interriat. Verein. Limnol.*, Vol 21, pp 1492-1496.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Overseas Surveys of Biocontrol Agents for Hydrilla

by
Joe K. Balciunas*

BACKGROUND

The continued spread of hydrilla in the United States along with the environmental restrictions and high cost of herbicides to control this aquatic weed have led to increased interest in biological methods to control this pest. This report presents the preliminary findings at a 21-week trip (24 May-18 October 1983) to Southeast Asia, New Guinea, Australia, and India (see Figure 1). This was the third in a series of overseas trips in search of natural enemies of hydrilla. Collecting at areas not visited during the previous two trips was emphasized during this trip. All three trips have been preliminary surveys. The objective has been to find as many hydrilla-damaging insect species as possible. The strategy for accomplishing this has been to collect at as many different hydrilla sites as time, funds, and local conditions will permit. Evaluation of any particular insect species host specificity and biological control potential will be done on future trips, which will emphasize intensive, long-term studies at selected countries.

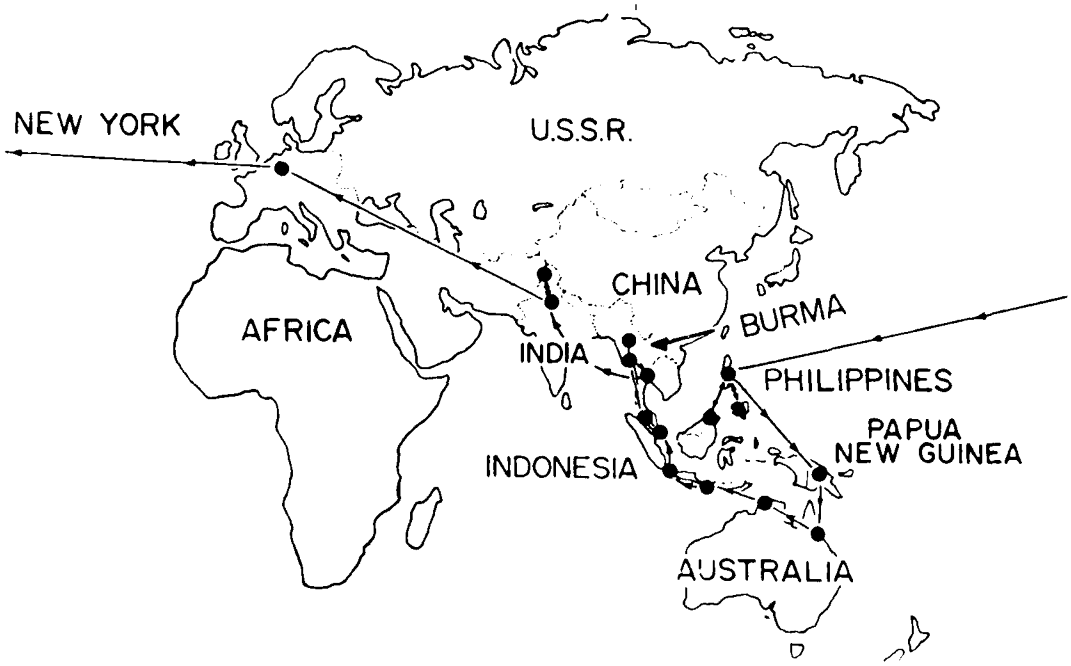


Figure 1. General route of 1983 trip searching for natural enemies of *Hydrilla verticillata*

* U.S. Department of Agriculture, Fort Lauderdale, Florida.

Specific locations visited during this third trip were the Philippine islands of Luzon and Mindanao, Sabah (North Borneo), Papua New Guinea, the northern portions of the Australian states of Queensland and Northern Territory, the Indonesian island of Bali, Penang - an island off the northwest coast of peninsular Malaysia, Central and Southern Burma, and Kashmir in northern India.

Figures 2-6 depict some of the species of hydrilla-damaging insects collected during this third trip.

Figure 2. Head and thorax of a *Parapoynx* sp. caterpillar found feeding on hydrilla at Laguna de Bay, Luzon, Philippines

Figure 3. Head and thorax of a *Parapoynx* sp. caterpillar found on hydrilla at Lake Kotubu, Papua New Guinea

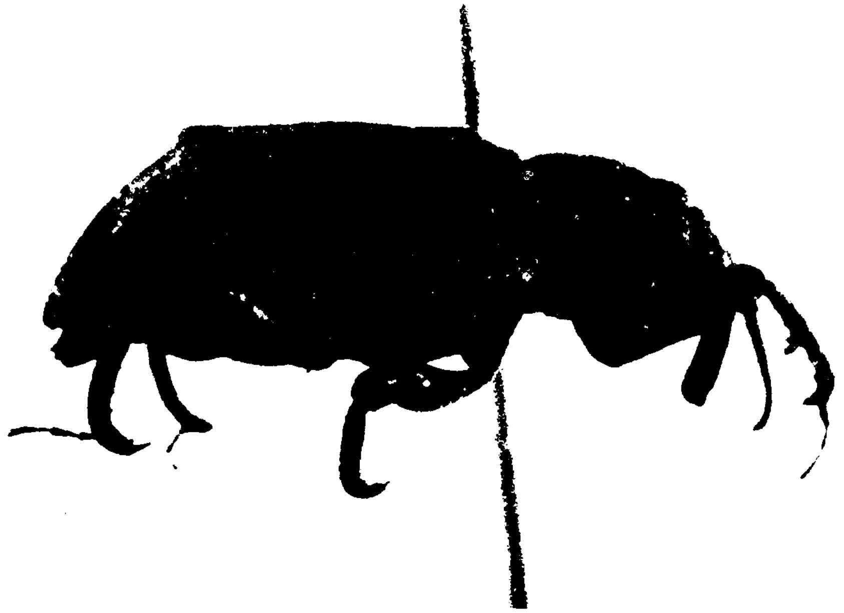


Figure 4. Close-up of a *Bagous* sp. weevil collected on hydrilla at Kakadu National Park, Australia

Figure 5. Clockwise from upper left, a pupae, adult male, adult female, and larvae of a *Hydrellia* sp. fly, collected from hydrilla at Kakadu National Park, Australia. These larvae mine the leaves of hydrilla and can sometimes cause severe damage to the plant, even when hydrilla is growing a considerable distance from shore

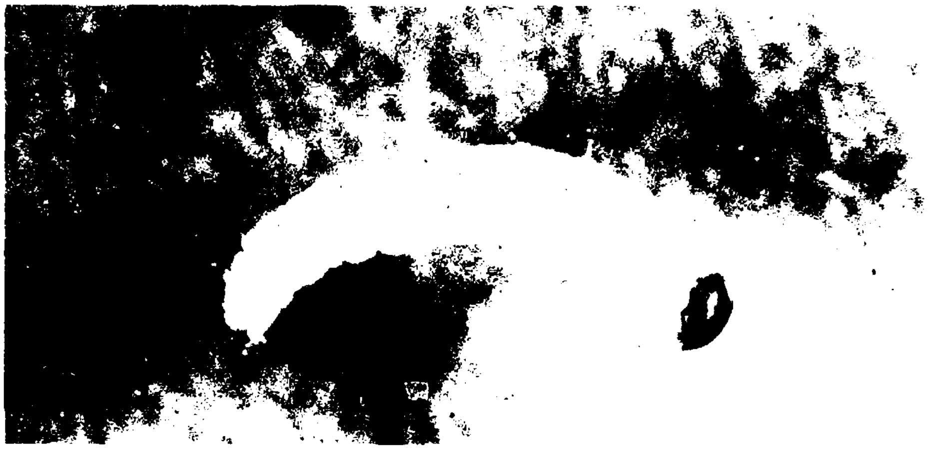


Figure 6. Larva of *Bagous* weevil. These larvae were found damaging hydrilla and Eurasian watermilfoil at Dal Lake, Kashmir, India

CONCLUSIONS AND RECOMMENDATIONS

The focus of this third overseas trip was to collect at areas not visited on the previous two trips. However, a month's delay in my departure date resulted in my arriving at many sites during the monsoon rains when hydrilla was difficult to locate and the insects associated with it were at low population levels. Nevertheless, additional hydrilla-damaging insect species were collected. Table 1 presents a very preliminary compilation of the insects and other organisms collected on hydrilla during this trip. Many specimens, especially from the ultraviolet light collections, remain to be sorted and identified.

During this trip weevils were collected in Australia and in Kashmir India. Thus, during the past three trips, at least 15 species of *Bagous* along with 5 other species of weevils have been collected. These weevils are of special interest because weevils are frequently host specific and have been used successfully in controlling water-hyacinth, *Salvinia molesta*, and a variety of terrestial weeds.

The three or four moth species, primarily members of the genus *Parapoynx*, collected during these trips also deserve more intensive scrutiny. Moth larvae are voracious feeders, and the adults disperse readily, thus making them ideal biocontrol agents if they are found to be sufficiently host specific.

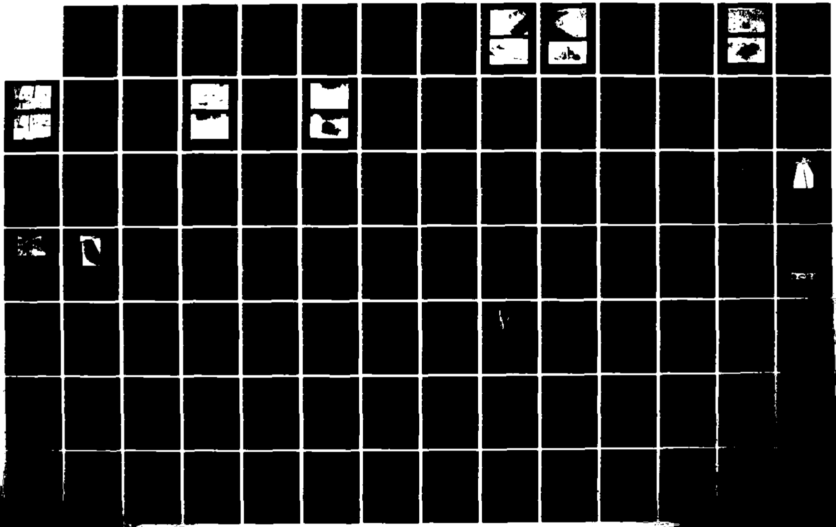
The leaf-mining flies, especially in the genus *Hydrellia*, also have been observed to damage hydrilla and at times are extremely abundant. Unlike the weevils, they also attack hydrilla growing at considerable distance from shore.

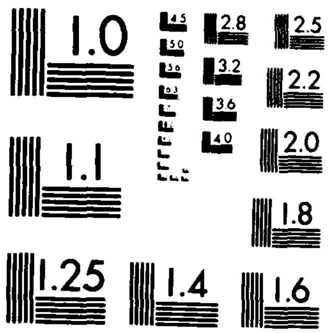
Since the emphasis of these three trips has been on collecting at as many hydrilla sites as possible, only a short time was spent at any particular site. Long-term testing of host specificity and efficacy of the most promising insect species will be conducted during future trips.

Of the areas visited during this trip, Australia, Kashmir, and the Philippines show the most promise.

AD-A142 827 PROCEEDINGS OF THE ANNUAL MEETING AQUATIC PLANT CONTROL 2/3
RESEARCH PROGRAM (..(U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS ENVIR.. JUN 84

UNCLASSIFIED WES/MP/A-84-4 F/G 6/6 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 1. INSECTS AND OTHER INVERTEBRATES COLLECTED ON HYDRILLA VERTICILLATA IN ASIA AND AUSTRALIA (JUNE - OCTOBER, 1983).

INSECTS:

ORDER COLEOPTERA (BEETLES)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Curculionidae			
Bagous species	India	5	KAS832Z1
Undetermined Bagoini	Australia	3	NTR832Z2
Dytiscidae	Australia	1	QLD832Z2
	Burma	1	BUR83203
	New Guinea	1	PAP832Z5
	Philippines	1	LUZ832Z2
Elmidae	Australia	3	QLD832Z2
Hydrophilidae	Australia	1	NTR832Z2
	Indonesia	1	BAL83201
	Philippines	3	LUZ832Z2, LUZ83202, MDN83201
Undetermined Coleoptera	Philippines	4	LUZ83202, LUZ832Z2, MDN832Z2
	Total	24	

ORDER DIPTERA (TRUE FLIES)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Ceratopogonidae	Australia	1	QLD832Z2
	Malaysia	1	PEN832Z1
	New Guinea	15	PAP83205, PAP832Z5, PAP832Z6
	Philippines	91	MDN832Z1, MDN832Z2, MDN832Z3
Chironomidae	Australia	12	NTR83201, NTR832Z1, NTR832Z2, QLD83202
	Burma	4	BUR83201, BUR83203
	India	2	KAS83202
	Malaysia	1	PEN832Z1
	New Guinea	144	PAP83205, PAP83206, PAP832Z6
	Philippines	32	LUZ83201, LUZ832Z1, LUZ832Z2, MDN83201, MDN83202, MDN832Z1, MDN832Z2
Culicidae	Indonesia	1	BAL832Z1
Ephydridae			
Hydrellia spp	Australia	82	NTR83201, NTR83202, NTR832Z1,
Undetermined Ephydridae	India	1	KAS832Z1
	New Guinea	1	PAP83205
	Philippines	1	MDN832Z2
Psychodidae	Australia	4	NTR832Z2
Simulidae	Philippines	1	LUZ832Z2
	Total	394	

TABLE 1 CONTINUED.

ORDER EPHEMEROPTERA (MAYFLIES)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Baetidae	Australia	3	NTR83201, NTR832Z2
Caenidae	Australia	1	NTR83202
	Total	4	

ORDER HEMIPTERA (TRUE BUGS)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Belostomatidae	Australia	7	NTR83201, NTR832Z1
	New Guinea	2	PAP83205
Corixidae	Australia	10	NTR83201, NTR83202, NTR832Z1, NTR832Z2
	Burma	5	BUR83201, BUR83203, BUR832Z1, BUR832Z2, BUR832Z3
	Malaysia	1	PEN83201
Gerridae	New Guinea	2	PAP832Z5
Mesoveliidae	New Guinea	4	PAP83205, PAP832Z4
Naucoridae Pelocoris sp	Burma	2	BUR83201
Notonectidae	Australia	1	NTR832Z1
Pleidae Plea sp	Australia	35	NTR83201, NTR83202, NTR832Z1, NTR832Z2
	Burma	16	BUR83201, BUR83202, BUR832Z1, BUR832Z2
	Malaysia	7	PEN832Z1
	New Guinea	4	PAP83205, PAP832Z4
Veliidae	Australia	9	NTR83201, QLD83202
	Malaysia	1	PEN832Z1
	Total	106	

ORDER HYMENOPTERA (BEES AND WASPS)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Braconidae	Australia	2	NTR83201, NTR83202
	Total	2	

ORDER LEPIDOPTERA (BUTTERFLIES AND MOTHS)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Pyralidae Parapoynx dicentra	Australia	75	NTR83201, NTR83202, NTR832Z1, NTR832Z2, QLD83201

TABLE 1 CONTINUED.

Parapoynx diminutalis	Burma	1	BUR83202
	Malaysia	17	PEN832Z1
Parapoynx spp	India	2	KAS832Z1, KAS832Z3
	New Guinea	4	PAP83206, PAP832Z6
Undetermined Pyralidae	Australia	5	QLD83202, QLD832Z1
	Philippines	6	LUZ832Z1, LUZ832Z2, MDN83202, MDN832Z3
	Total	110	

ORDER ODONATA

NAME	COUNTRY	SPECIMENS	COLLECTIONS
SUBORDER ANISOPTERA (DRAGONFLIES)			
Aeschnidae	New Guinea	3	PAP83205
Libellulidae	Australia	2	NTR83202, QLD832Z1
	New Guinea	2	PAP83205
SUBORDER ZYGOPTERA (DAMSELFLIES)			
Coenagrionidae	Australia	20	NTR83201, NTR83202, NTR832Z1, NTR832Z2, QLD83202
	Burma	12	BUR83201, BUR832Z1, BUR832Z2
	India	2	KAS832Z1
	Malaysia	6	PEN83201, PEN832Z1
	New Guinea	10	PAP83203, PAP83205, PAP832Z1, PAP832Z3, PAP832Z5
	Philippines	2	LUZ832Z1
	Total	59	

ORDER TRICHOPTERA (CADDISFLIES)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Hydroptilidae Orthotrichia species	New Guinea	3	PAP83206
Leptoceridae Leptocerus species	Burma	1	BUR83201
Oecetis spp	Australia	5	NTR83202, NTR832Z2
	New Guinea	11	PAP83205, PAP83206
	Total	20	

OTHER INVERTEBRATES:

CLASS ARACHNIDA
SUBCLASS ACARI (MITES)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Aquatic Mites	Australia	7	NTR832Z2, QLD83202, QLD832Z2
	Burma	1	BUR83202
	Malaysia	1	PEN832Z1
	New Guinea	50	PAP832Z2
	Total	59	

TABLE 1 CONTINUED.

CLASS CRUSTACEAE

NAME	COUNTRY	SPECIMENS	COLLECTIONS
ORDER AMPHIPODA (SCUDS)	Philippines	1	LUZ832Z2
ORDER DECAPODA (CRAYFISH, CRABS, & SHRIMP)			
Shrimp	Australia	7	NTR83201, NTR83202, QLD83202
	Burma	9	BUR83201
	Philippines	5	LUZ83202, LUZ832Z2
ORDER OSTRACODA (SEED SHRIMP)			
Undetermined sp	Burma	4	BUR83201, BUR83203, BUR832Z3
	Malaysia	2	PEN832Z1
ORDER TANAIDACEA (TANAIDS)			
Undetermined sp	Philippines	5	LUZ832Z1, LUZ832Z2

	Total	33	

CLASS MOLLUSCA (SNAILS AND CLAMS)
ORDER GASTROPODA (SNAILS)

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Hydrobiidae	Burma	3	BUR83201, BUR832Z1, BUR832Z2
	New Guinea	14	PAP83203, PAP83206
Lymnaeidae	Burma	4	BUR83202, BUR832Z2
	India	3	KAS832Z1, KAS832Z3, KAS832Z4
Physidae	Australia	22	NTR83201, NTR83202, NTR832Z1
	Burma	6	BUR83202, BUR832Z2, BUR832Z3
	Indonesia	35	BAL83201, BAL832Z1
	Malaysia	13	PEN83201, PEN832Z1
	New Guinea	21	PAP83203, PAP83205, PAP83206, PAP832Z3, PAP832Z4
	Philippines	1	MDN83201
Planorbidae			
Gyraulus spp	Australia	3	NTR83201, NTR832Z1
	Burma	304	BUR83201, BUR83202, BUR83203, BUR832Z1, BUR832Z2, BUR832Z3
	Malaysia	1	PEN832Z1
	New Guinea	40	PAP83203, PAP832Z3
	Philippines	3	LUZ83202
Helisoma spp	Burma	3	BUR83202, BUR832Z2
	Indonesia	8	BAL83201, BAL832Z1
	Malaysia	2	PEN83201, PEN832Z1
Pleuroceridae	Burma	5	BUR83202, BUR83203
	Indonesia	1	BAL83201
	Malaysia	25	PEN83201, PEN832Z1
	New Guinea	40	PAP83203, PAP832Z2, PAP832Z3
	Philippines	35	LUZ83201, LUZ83202, LUZ832Z1, LUZ832Z2
Viviparidae	Australia	1	NTR83201
	Burma	1	BUR832Z2
	Indonesia	15	BAL83201, BAL832Z1
	Malaysia	1	PEN83201

	Total	610	

TABLE 1 CONTINUED.

CLASS OLIGOCHAETA

NAME	COUNTRY	SPECIMENS	COLLECTIONS
Oligochaet Worms	Australia	2	NTR83201
	New Guinea	22	PAP83222
	Philippines	1	LUZ83201
	Total	25	

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Studies on the Biological Control of Waterhyacinth with the Weevils *Neochetina eichhorniae* and *N. bruchi*

by

Ted D. Center* and Willey C. Durden*

BACKGROUND

The South American waterhyacinth weevils *Neochetina eichhorniae* and *N. bruchi* (Coleoptera:Curculionidae) were extensively tested from 1968-1974 in Argentina to determine their potential as biological control agents of waterhyacinth *(Eichhornia crassipes* (Mart.) Solms. :Pontedoriaceae). In 1972 *N. eichhorniae* was first released on waterhyacinth in the United States, and release of *N. bruchi* followed soon after in 1974 (Figures 1 and 2). Today one or both of these species have been released in Florida, Georgia, Louisiana, Mississippi, Texas, California, Australia, Egypt, the Sudan, India, Figi, Indonesia, South Africa, Thailand, Zambia, and Zimbabwe. Reports on efficacy have been slow in coming from most of those areas, but effective control has been reported in Australia, the Sudan, Florida, Louisiana, Texas, and even at a site in Argentina.

Although several independent studies designed to document the results of waterhyacinth biocontrol efforts have been conducted in the United States, the resultant information has not been extensively reported or well documented. In fact, no published record exists which lists original release sites. It was the purpose of this project to assemble all information and data on release of both species of weevils and subsequent follow-up studies of their effects on waterhyacinth and to compile these data as a comprehensive report. This paper represents a brief summary of that report.

A pyralid moth, *Sameodes albiguttalis* ~~(Figures 3 and 4)~~, was later released in 1977 and proved effective but under rather restrictive circumstances. This insect was the subject of a detailed report submitted to the Corps of Engineers Aquatic Plant Control Research Program in FY 1983 and will not be extensively dealt with here.

APPROACH

The approach used in putting the report together involved compilation of old records into computerized data files, updating of current data files, reexamination of original release sites, acquisition of new comparative data from original study sites, integration and interpretation of these data and information, and then organization into a report format.

Because of the number of years included, and a continual turnover in the researchers involved, consistency in approach was lacking when compared among

* U.S. Department of Agriculture, Fort Lauderdale, Florida.

Figure 1. A waterhyacinth weevil, *Neochetina eichhorniae*, adult female

Figure 2. An adult male *Neochetina bruchi*

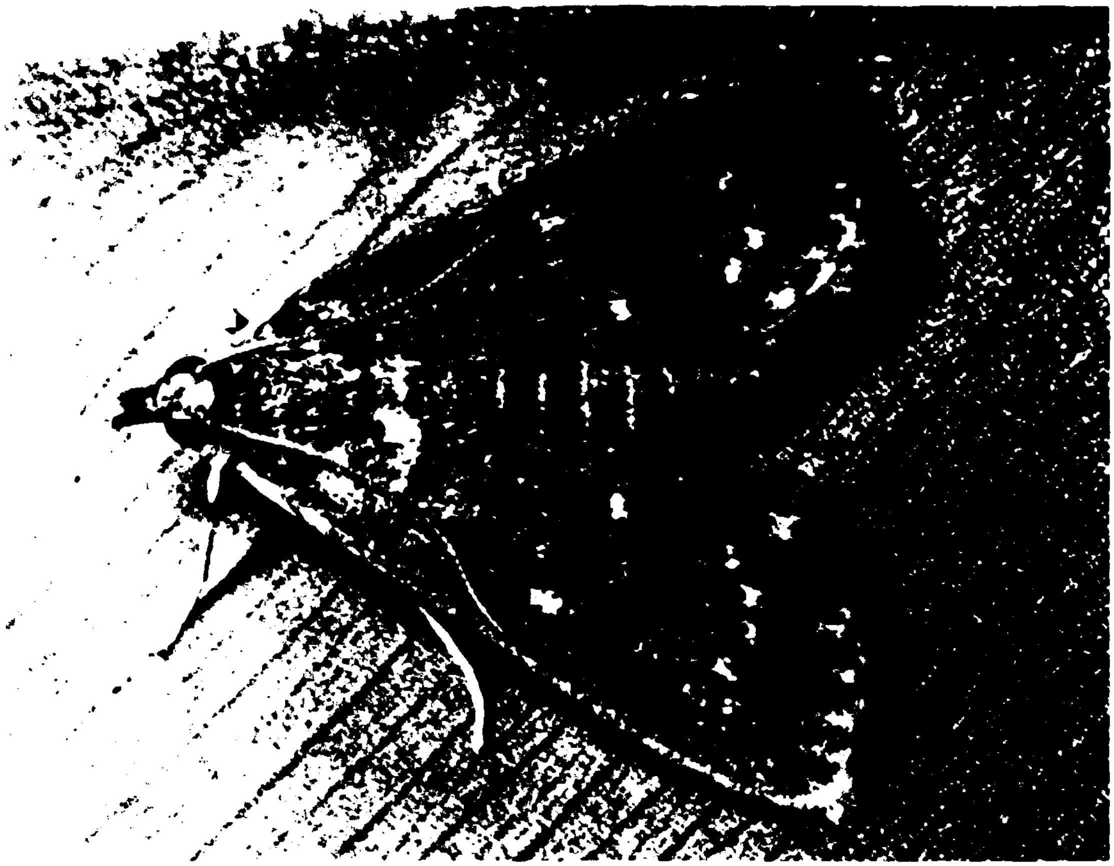


Figure 3. A waterhyacinth moth, *Sameodes albiguttalis*, adult female

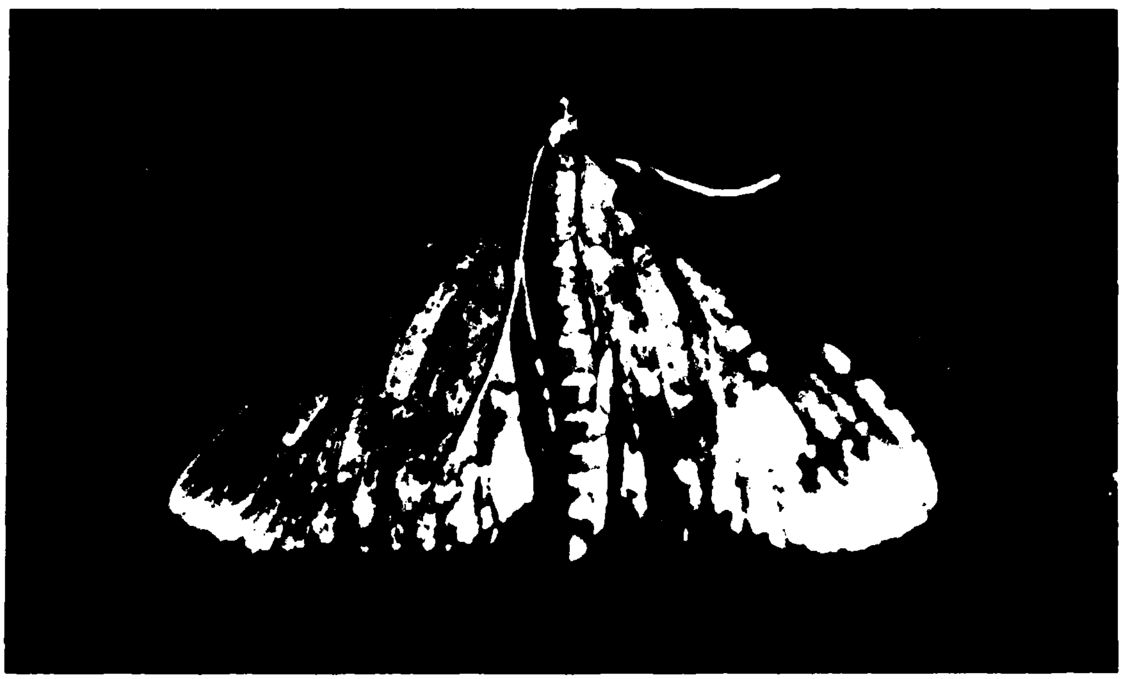


Figure 4. An adult male waterhyacinth moth

projects. Nevertheless, many common trends and patterns were observable. Data generally consisted of (a) individual plant characteristics such as height and number of leaves; (b) characteristics of the plant population such as biomass or shoot density; (c) the degree, severity, or amount of insect and/or pathogen damage to the individual shoots; and (d) characteristics of the insect population such as numbers per shoot or per square metre of larvae, pupae, and adult weevils.

Several peripheral studies dealing with the biologies and interaction between the weevils and the host plant were also included by extracting data from exploratory studies. One section, for example, deals with the possibility of using number of weevil feeding scars on leaves as a means of estimating numbers of adult weevils. Data are compared for this purpose between Florida and Queensland, Australia. A second section examines the spatial dispersion of adult feeding on waterhyacinth shoots, and a third examines dispersion of eggs and larvae in relation to leaf production and turnover. The remainder of the report focuses upon specific sites in Louisiana and Florida and provides case histories which document the effects of the weevils.

CURRENT STATUS AND ACCOMPLISHMENTS

Organization of all of the diverse data has been more difficult than expected. Write-ups for all results from the Gainesville laboratory (pre-1978) and for the Fort Lauderdale laboratory since 1978 are complete. Thus far five sections have been completed which amount to 121 pages, 34 figures, and 9 tables. Write-ups for the portions of the report dealing with Louisiana, Mississippi, and Texas and with pre-1978 data from Fort Lauderdale remain to be completed. It is anticipated that the remaining section will be completed within FY 1984. A summary of the completed portion of the report follows.

SYNOPSIS

First releases of *N. eichhorniae* and *N. bruchi* were carried out in south Florida through cooperative efforts of the U.S. Department of Agricultural (USDA), the Corps of Engineers, and the Florida Department of Natural Resources. The very first release on *N. eichhorniae* was made on 23 August 1972 at a borrow pit north of Cypress Creek Road in Fort Lauderdale, Broward County, Florida. By November 1973, releases had been made at 53 sites, six of these were in Gainesville, Fla., one was in New Orleans, La., one was in Texas, and the remaining 45 were south of Lake Okeechobee in Florida. By 20 April 1977, a total of 201 releases had been made throughout the southeast and no attempt was made to document further releases after that time.

In contrast to *N. eichhorniae*, only 24 releases of *N. bruchi* were made throughout the State of Florida between 1 July 1974 and 27 October 1976. Although additional releases were made in other states by cooperating agencies, we do not have these records. Although care was taken to release *N. bruchi* at sites where *N. eichhorniae* was not present, *N. eichhorniae* successfully invaded every site and in some cases encroachment was noted within 6 months. Because of these mixed populations, the relative inseparability of the larvae, and the similarity of damage caused, effects of the two species were inseparable.

Cypress Creek site

The first release site for *N. eichhorniae* was in north Fort Lauderdale, Broward County, Florida, near Cypress Creek. It consisted of a 40-acre borrow pit which was full of tall, robust waterhyacinth plants. Weevils were released here on 23 August 1972. Construction of an interstate highway through the site, however, included a dike which effectively impounded the study area resulting in a stagnant situation with low nutrient flux. The waterhyacinth coverage persisted but the plants subsequently became smaller. Weevil infestation ultimately caused many plants to drop out. Many openings in the mat resulted by November 1975 and the mat was being invaded by terrestrial and emergent plant species. By November 1976, the site was entirely overgrown by other weeds and waterhyacinth was a minor component of the community. When the Interstate highway was completed, the dikes were re-opened and water flow to the site was restored. This resulted in a minor recovery of the waterhyacinth population but it never regained the vigor of the population that was there prior to release of the weevils. The site was eventually destroyed by commercial development of the area.

Boca Raton site

On 26 October 1972 weevils were released at a small pond (ca. 1 acre surface area) near Boca Raton, Fla. The site was a shallow fishing pond which had been artificially diked off and was fed by drainage from an adjacent cypress swamp. The waterhyacinth shoots here were smaller than average, appeared stunted and spindly, and their leaves were characterized by a tough, leathery texture. Besides the low pH resulting from the water source, there was probably very little flow through the area and low nutrient concentrations. Nonetheless, the pond was entirely covered with waterhyacinth when observations were made in June 1973 (Figure 5). By September 1973, plants at the center of the pond began to drop out. By March 1974, shoots were sparsely dispersed throughout the site with a great deal of open water area interspersed amongst the plant population. By November 1974, a diversity of plants had invaded the waterhyacinth mat and a year later few waterhyacinth shoots remained. Leaves of those few were severely damaged by weevils and were brown and curled. In May 1977 (Figure 6), waterhyacinth was sparse, and weedy vegetation occurred within the dying waterhyacinth mat. The small island of floating weeds disappeared as the waterhyacinth decayed. At the last observation in December 1977, the pond was completely open although a few heavily damaged waterhyacinth plants persisted around the shoreline. Ultimately this site was also lost to condominium development.

Orchid Isles site

This site was unique for several reasons. It was located south of Tamiami Trail and was one of the most southerly weevil release sites. Plant growth conditions remained stable for a prolonged period and the original waterhyacinth population persisted for 6 to 7 years. Because of this apparent stability, it was selected as a release site and subsequent study area for efficacy of *N. eichhorniae* and *S. albiguttalis*. Waterhyacinth infested with *N. eichhorniae* were moved to the site on 11 October 1973 and *S. albiguttalis* was released there in June and July 1978. Data were collected monthly over a period of 17 months beginning in September 1978.

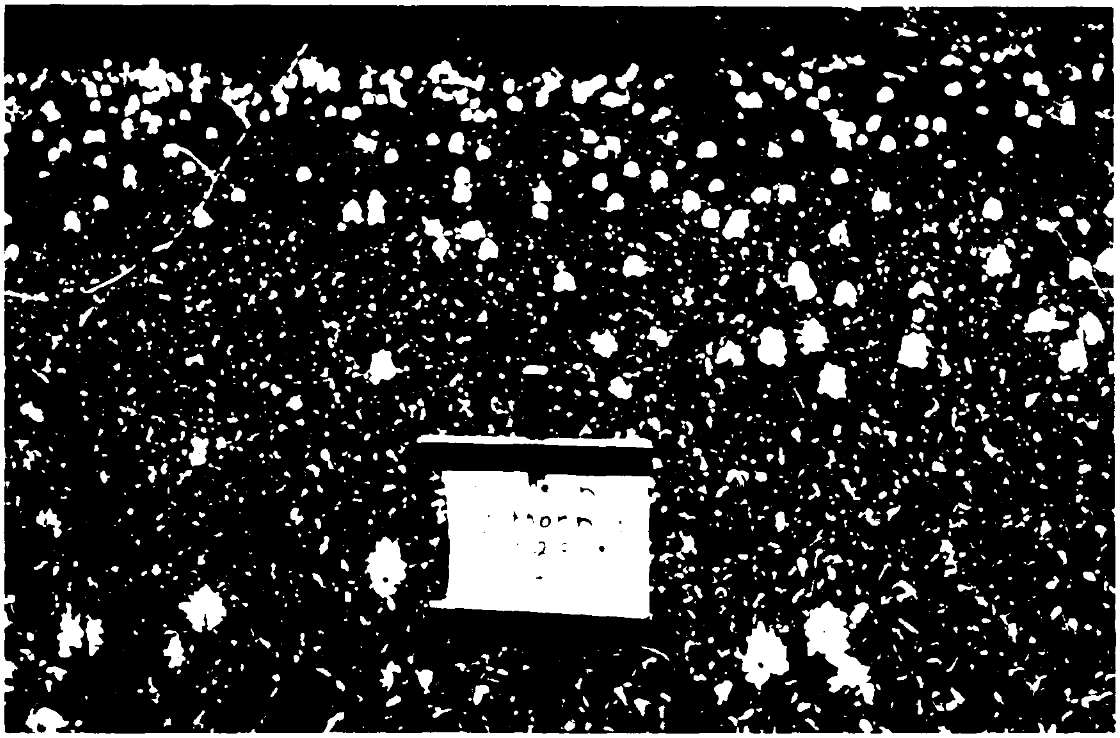


Figure 5. The Boca Raton site in June 1973 showing the entire surface of the pond covered with waterhyacinth

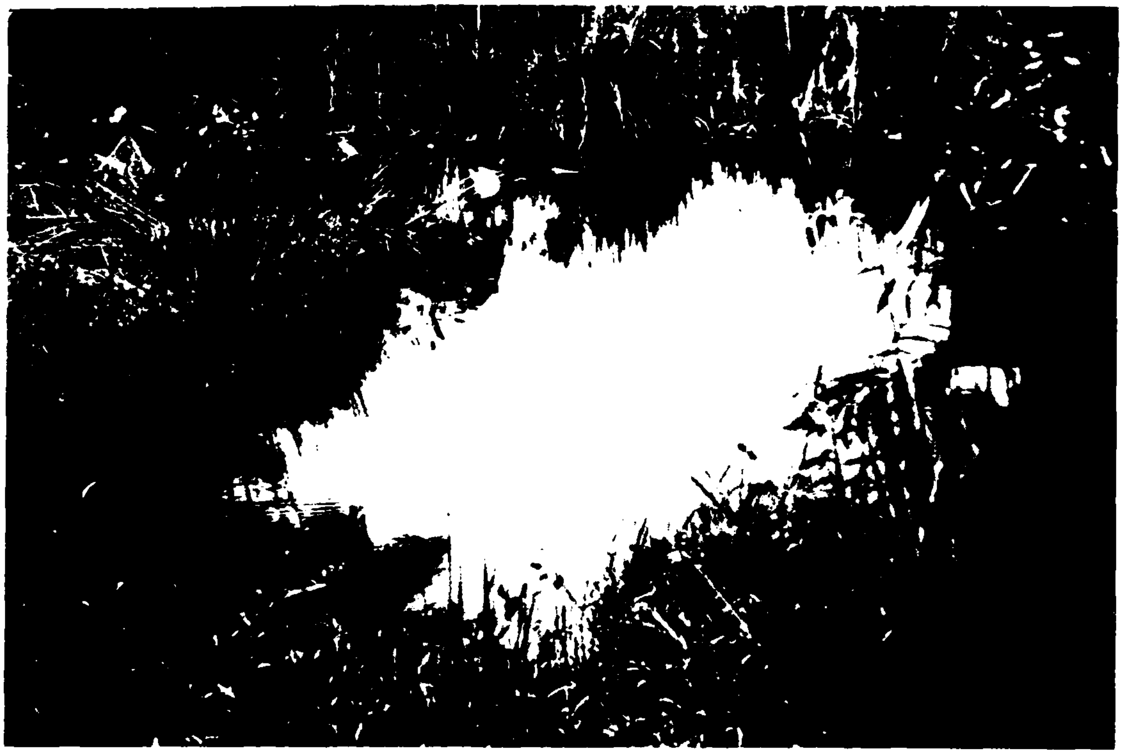


Figure 6. By May 1977 waterhyacinth was sparse in the Boca Raton site and terrestrial and emergent vegetation had rooted within the dying waterhyacinth mat. The floating island later dropped out

Figure 7 shows the general appearance of the area and the waterhyacinth plants within the site. Since this was a persistent population and because conditions remained relatively stable, the general appearance of the plants changed very little from month to month or even year to year. This stability changed between 1980 and 1983, however. Weevil numbers and the consequent plant damage increased greatly between 1978 and 1979. In addition, infestation by the waterhyacinth mite (*Orthogalumna terebrantis*) appeared to increase and spider mites began to occur more frequently between 1979 and 1980. These factors coupled with stress from drought in spring and summer 1981 resulted in drastically reduced coverage. The few shoots remaining in the area in April 1983 were heavily damaged by weevils. The waterhyacinth population failed to recover after 2 years even though shoots were present.

Palmdale site

On 23 September 1975, 73 adult *N. bruchi* were released at a site near Palmdale, Glades County, Florida. The site was a river swamp which flowed west but was impounded by a highway, thus forming a shallow pond which was covered with waterhyacinth. The plants were ca. 50 cm tall, with attenuate leaf petioles, and were lush and healthy forming a closed mat. In December 1977 the waterhyacinth began to decline following a peak in weevil activity. A severe frost occurred in February 1977 which should not have permanently affected the plants when one considers conditions they recover from in the northern part of their range. Nonetheless, the plants never fully recovered and remained less than 13 cm tall through the entire year. By September weevil damage was severe, leaves were brown and curling, and shoot density had declined from 83 sq m in August to 35 sq m in September. A peak of weevil activity occurred in October when numbers reached 2.3 weevils per shoot, a very high average for such small shoots.

Unfortunately, in early March 1978 this area was sprayed with herbicide, but by late March the site was covered by a high density of small, healthy robust shoots typical of regrowth from chemical treatment. By April weevil damage was again severe; the plants were small, spindly, and sparse; and open water was appearing within the mat. In May the site was sprayed again and the plants were gone in June. By May 1979, a healthy population of waterhyacinth was again present but the drought of 1981 dried up the site. When last examined in March 1983 the water level was up and the site was covered with waterlettuce (*Pistia stratiotes*) but waterhyacinth was not present. Weevils nearly controlled waterhyacinth here several times, but man-made or natural perturbations prevented observation of the final outcome. Waterhyacinth always recovered from these perturbations in better condition than they were in before and usually with very little insect infestation. Subsequent declines would then result from buildup of weevil populations. We suspect that this pattern recurred after the drought and that weevils ultimately eliminated the plants.

Homeland site

On 19 May 1976, *N. bruchi* was released at a site just south of Homeland, Polk County, Florida. The site was a slough which drained marshlands interspersed with hardwood forest and which fed into the Peace River. The area was large and

Figure 7. The Orchid Isles site showing the resident waterhyacinth population in November 1979

Figure 8. The Orchid Isles site cleared of waterhyacinth as a result of several stress factors including weevils, mites, and the 1981 drought. By April 1983, a few shoots remained but these were heavily fed upon by weevils and they failed to recolonize the site

completely covered with large, healthy, lush waterhyacinth. For example, in June 1976, the average height of the shoots was 75 cm and by September it was 97 cm. In June, within 1 month after release, 45 percent of the shoots in the immediate release area showed signs of weevil feeding and by August this increased to 100 percent.

Between November 1976 and November 1977, the size of the leaf laminae decreased from 17 × 13 (length × width) to 12 × 9 cm and length of petioles decreased from 70 to 52 cm. By September 1978 lamina size changed somewhat to 12 × 12 cm but petiole length decreased further to 22 cm. Shoot density changed dramatically over the years, in particularly during summer 1983. In July 1976, average density was 64 shoots per square metre; in June 1978 density averaged 90 shoots per square metre whereas it had been 76 per square metre in March and 68 per square metre in May. By August 1968, it declined to 60 shoots per square metre, but by August 1983 shoot density averaged only 29 shoots per square metre.

Weevil numbers were quite high at this location and by July 1977 it was noted that the population consisted of a mix of *N. eichhorniae* and *N. bruchi*. In August 1977 0.8 and 0.6 adult *N. eichhorniae* and *N. bruchi*, respectively, were collected per shoot. By September, averages changed to 0.3 and 1.5 *N. eichhorniae* and *N. bruchi*, respectively, but the species ratio reversed in October when averages were 1.3 and 0.3 adults per shoot. By July 1978, adult weevils averaged 6 per shoot (42 percent *N. bruchi*), 4.5 by August (78 percent *N. bruchi*), and 8.8 by September (66 percent *N. bruchi*). In 1983 adult weevils averaged 0.7 per shoot (43 percent *N. bruchi*) in May and 2.5 per shoot by August (7 percent *N. bruchi*).

The decline in plant density noted by summer 1983 was due to the activity of the weevils, which reduced plant vigor, and to competition from emergent vegetation, which invaded the mat and usurped space. By 1983, waterhyacinth coverage had been reduced by 75 to 80 percent. The type of plant present had changed from the large, lush, deep green type to a small, spindly type with tough, hard leaves. Because *N. eichhorniae* colonized the site and species ratios varied so greatly, it is impossible to ascribe the decline in plants to the effects of one weevil species over the other.

Lake Alice site

In 1974, waterhyacinth covered nearly all of Lake Alice, a 32.2-ha eutrophic lake in Gainesville, Alachua County, Florida. Release of *Neochetina eichhorniae* caused profound changes in the marsh community. Waterhyacinth exhibited reduced growth rates, a prolonged period of net growth, less seasonal variation in shoot density, and delayed phenology. Ceiling yield changed from 2.5 kg/m^2 to 1.5 kg/m^2 and shifted from June to September. Canopy height changed from a June maximum of over 100 cm to an autumnal maxima of 80 cm or less.

A native herbivore, the noctuid *Bellura densa* Wlk., was not a significant factor in the dynamics of the waterhyacinth population. Larvae never exceeded 12 per sq m and never damaged more than 20 percent of the leaves. Although relatively common in 1974, *B. densa* became rare and none were found in 1980.

After release in February 1974, *N. eichhorniae* expanded radially from the release point and by fall 1975 occurred throughout the waterhyacinth population. Larval and pupal numbers peaked twice annually, the former in spring and late

summer and the latter in early summer and fall. Adult numbers showed less distinct peaks with continuous buildups through summer and maximum average numbers of three to four weevils/shoot during August to October. Leaf damage caused by larval and adult feeding paralleled larval and adult population trends.

Reduction of the tall monolayered waterhyacinth canopy resulted in invasion of the mat by other plants and increased diversity of the floating community. Waterhyacinth acreage declined from a variable 17.5 to 25.3 ha in 1974 to 1.6 ha in 1982. *Hydrocotyle* spp., *Typha* sp., *Leersia* sp., *Salix* sp., *Ludwigia* sp., and others established in the floating mat along with the formerly dominant waterhyacinth.

The pathogen *Acremonium zonatum* and the oribatid mite *Orthogalumna terebrantis* infested old leaves when leaf production rates were low. Spider mites *Tetranychus urticae* occurred sporadically, affected all leaf age cohorts, but caused only minor leaf damage. The weevils *N. eichhorniae* in conjunction with normally nonpathogenic secondary bacterial and fungal infections caused severe damage to the waterhyacinth population. This, in conjunction with increased competition from invading plant species, has reduced the status of waterhyacinth at Lake Alice to a minor component of the marsh community.

Canal M, West Palm site

Canal M is a 12-mile-long section of canal located west of West Palm Beach, Palm Beach County, Florida, which provides the principal source of drinking water for the city. Studies were initially conducted here as a part of the evaluation of *Sameodes albiguttalis* and a section of canal was barricaded for use as a study area in December 1981. At that time only a fringe of plants existed along the shoreline and it was estimated that about 30 percent of the surface area was covered (Figure 9). The plants were small, lush, dark green in coloration and bore leaves with swollen petioles. By May 1982 the surface of the study area was completely covered with waterhyacinth (Figure 10) but damage caused by *S. albiguttalis* was extensive and severe. It was estimated that 31 percent of the shoots that were present the previous December had been killed by *S. albiguttalis* and an additional 43 percent by *N. bruchi*.

While the study area remained unaffected by weed control crews, the upstream section of canal adjacent to and east of the study area was not so protected. In March a large thrashing-machine type of harvester was used to mechanically destroy the plants. By early April most of the fragmented plants had died and all but a fringe of the canal was clear, but by May the canal had again grown over, the plants were extremely healthy, and it was difficult to discern that control had taken place. This provided an interesting contrast to the non-harvested study area which was solely under the influence of biological control.

Analyses of leaf budgets from 1982 revealed that insects were killing leaves in the biological control area slightly faster than the shoots were able to produce them (mortality rate = 0.124 leaves/day; production rate = 0.114 leaves/day). Extrapolating from this, all leaves produced should have been dead by December 1983 and these data formed the basis for a predictive capability. By March 1983, plants had become quite brown and unhealthy appearing, even though the canal remained full. By July, the plants were small (15 to 25 cm) and spindly and were beginning to sink

Figure 9. A fringe of plants which occupied ca. 30 percent of the biological control study area in Canal M on 23 December 1981

Figure 10. Waterhyacinth completely covered the biological control study area in Canal M by May 1982

(Figure 11). Indeed, many large holes were apparent within the mat where sections had dropped out. By November only a few petioles of very unhealthy plants remained and by early January 1984 the area was completely clear (Figure 12). By way of contrast, plants in the mechanical control area in January 1984 appeared to be similar to those in the biological control area in March 1983. These too were heavily damaged by insect attack but the cycle appeared to be lagging about a year behind. This competitive release caused by removal of plants reset the waterhyacinth population to logarithmic growth and, at the same time, eliminated most of the insects. This eliminated the control exerted by the insects and quickly recreated the problem. As a result it will now take longer to achieve comparable control in the mechanical control area. While biological control can never replace chemical or mechanical control, care must be taken and means devised whereby control methods do not interfere with one another.

Weevil population index

A cooperative project was undertaken between the USDA Aquatic Plant Management Laboratory in Fort Lauderdale and Mr. A. D. Wright of the Commonwealth Scientific and Industrial Research Organization, Long Pocket Laboratories in Brisbane, Queensland, Australia. Examination of data comparing the populations of adult waterhyacinth weevils (*Neochetina eichhorniae* Warner) with number of feeding scars on waterhyacinth leaves in Florida and Queensland, Australia, revealed a close relationship. Data analyzed using covariance produced nearly identical results for both countries even though data collection techniques differed. The empirical formula $I = 0.0366S^{0.7684}$, where I = weevils per plant and S = feeding spots per leaf, effectively predicted I for both countries. Also, intracountry variances were quite comparable and homogeneous between countries. Analysis of Florida data indicated seasonal differences in the relationship, and Queensland data indicated site to site differences. These differences were apparent in adjusted means but not in regression coefficients. Intraseasonal variances differed from season to season and intrasite variances differed from site to site, which violates the assumption of homogeneous variances in these latter analyses. Nonetheless, feeding spot counts adequately predict weevil numbers (and vice versa) and effects of the sample size and the number of feeding spots upon the fiducial limits of estimates of weevil populations are shown. This technique for estimating adult weevil populations is suitable for use in other regions where monitoring of progress in biological control of waterhyacinth is undertaken and its application, advantages, and limitations are discussed.

Within-shoot dispersion of weevil eggs and larvae

Two studies examined the dispersion of eggs and larvae of the weevil *Neochetina eichhorniae* within waterhyacinth shoots. Based upon dissection of whole plants, eggs were unusual in the youngest, uppermost leaves but were common in the mature leaves. Older larval instars occurred more frequently in older leaves, usually concentrated in the basal portion of the petiole, and, as instar increased, increasing proportions occurred within the stem (rhizome). In the other study, new leaves of plants were tagged so as to later identify age class. Shoots were first grown in small pools for varying durations, then transplanted to a field site. Tagged leaves

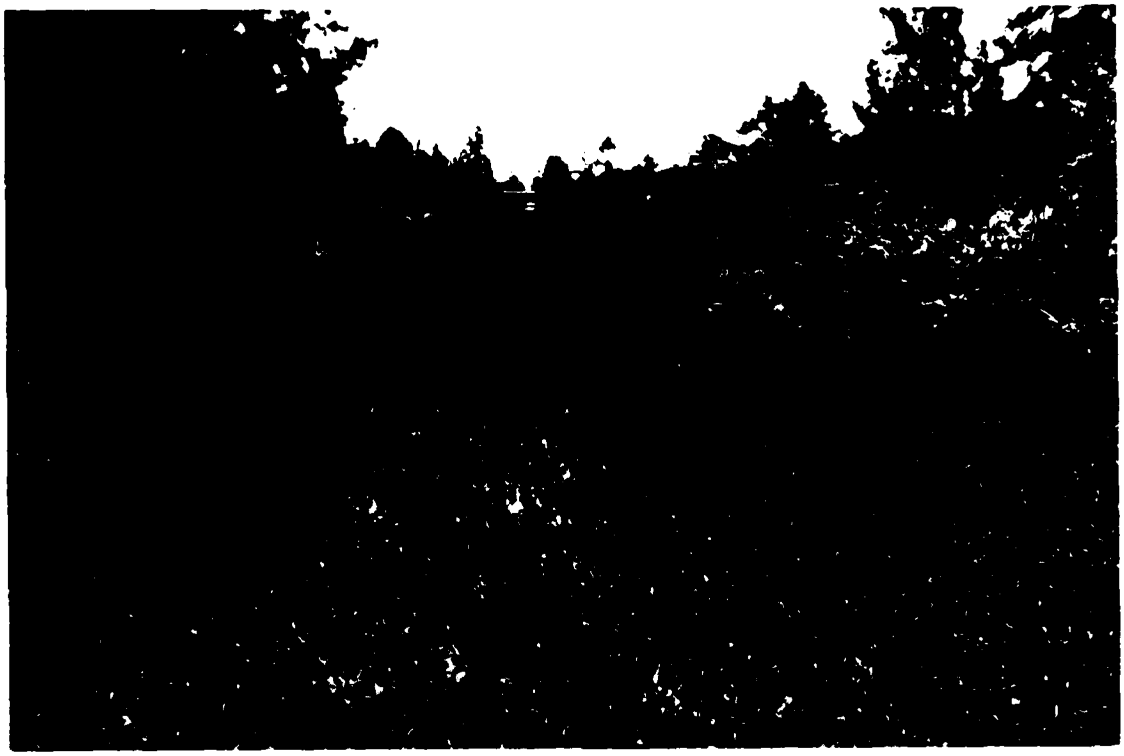


Figure 11. The waterhyacinth in the Canal M study area was devastated by insect attack and by July 1983 had begun to sink. Open water in the foreground was one of last areas to cover over and one of the first areas to fill in

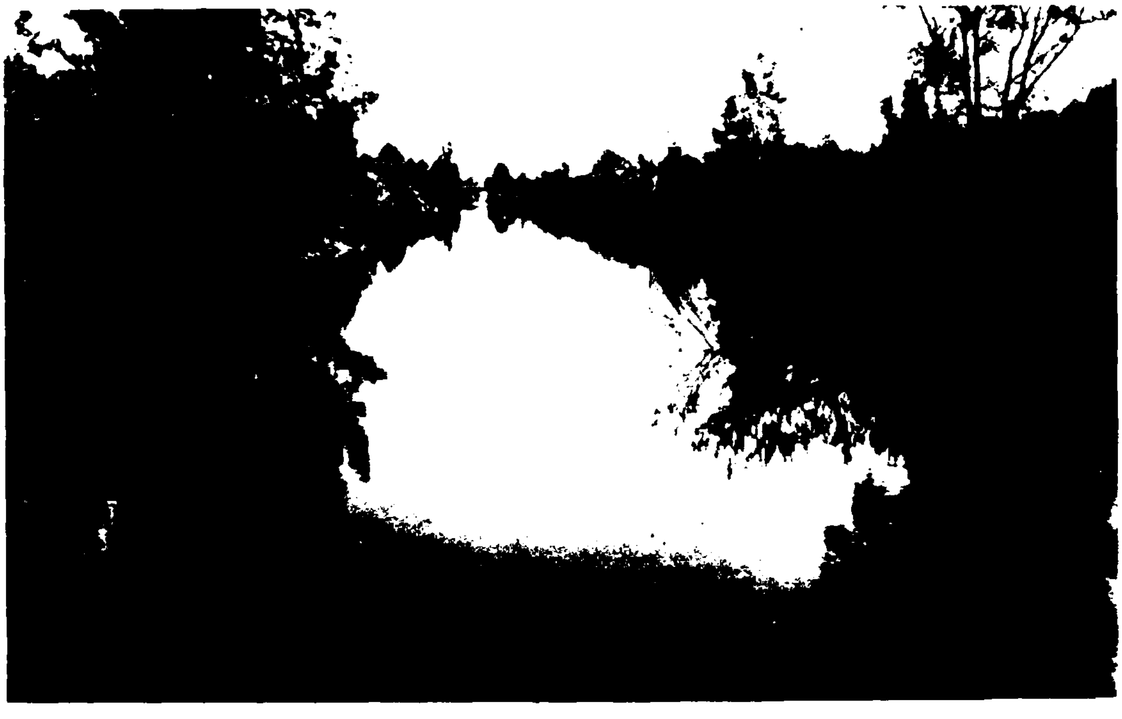


Figure 12. The Canal M biological control study area in early January 1984. Waterhyacinth were present but were few, occurred along the edge of the canal, and were in very poor condition from weevil infestation

were later harvested and dissected to determine if leaf age and duration of exposure to weevil populations influenced numbers of eggs and larvae in leaves. Leaf age explained 83 percent of the variation among age classes in average number of eggs per leaf, and more eggs were found in older leaves. Time in field accounted for 89 percent of variation in average number of larvae per leaf when standardized to percentages of the total found at each harvest. Dispersion of eggs seems determined by ovipositing females via selection of leaves within a specific age range while dispersion of larvae is strongly influenced by phyllotaxis.

It is suggested that selection of leaves for oviposition by female weevils is based upon distribution of secondary metabolic compounds and/or nutrients and that leaf senescense and ultimate sloughing of the leaf from the shoot could be a significant source of mortality to eggs and possibly larvae. Phyllotaxis seems to be an important driving force in the dispersion of the relatively immobile insects within waterhyacinth shoots. Third instar larvae, however, seem able to easily move within the shoot and are less affected by phyllotaxis. Movement by larvae to petiole bases probably maximizes chances of staying with the shoot if the leaf is separated.

Within-shoot dispersion of adult weevil feeding

A third study examined dispersion of feeding by adult waterhyacinth weevils. Adult weevils respond quantitatively and feeding declines in direct proportion to leaf age. Number of feeding spots on leaves increases at a declining rate with increasing duration of availability. Laboratory studies indicate that weevils prefer young leaves and eliminate the possibility that this is an artifact of the spatial arrangement of the leaves on the shoot. Olfactometer studies indicate that a volatile substance serves as an attractant and is more prevalent in young tissue. Weevils discriminate between young and old tissue. Reasons for greater feeding on young leaves are discussed.

CONCLUSIONS

Biological control of waterhyacinth is destined to become one of the landmark examples of successful control of an exotic weed by reassociation with its natural enemies. Data are presented in the upcoming report which demonstrate that biological control of waterhyacinth is (a) effective, (b) applicable in a wide variety of ecological systems, (c) predictable, (d) potentially fast-acting, as well as (e) persistent and self-sustaining. Effective control using insects is now being reported from throughout the United States and from around the world, and dollar savings have already been substantial.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Ten-Year Update of the Status of Alligatorweed in the Southeast

by
A. F. Cofrancesco, Jr.*

BACKGROUND

Alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb) has been present in the United States since 1897 and is currently distributed throughout the Southeast. This weed causes extensive problems in water systems by reducing or preventing navigation, fisheries, and other recreational use of the water.

During the 1950s, alligatorweed was found to be less susceptible to herbicides than most other aquatic plants, and research was initiated to examine alternate control methods. The U.S. Army Corps of Engineers (CE) funded a U.S. Department of Agriculture (USDA) search in the late 1950s for candidate biological agents for control of alligatorweed. The search was conducted in Argentina, a country where alligatorweed is native. Numerous insect species associated with alligatorweed were examined in Argentina for their efficacy and host specificity, and promising species were later tested in quarantine facilities in the United States. After 7 years of research, three insect species, the alligatorweed flea beetle (*Agasicles hygrophila* Selma and Vogt), the alligatorweed thrips (*Amynothrips andersoni* O'Neill), and the alligatorweed stem borer (*Vogita malloi* Pastrana), were approved for release in the United States.

In 1977, the USDA in cooperation with the CE published a technical bulletin describing the releases and initial impacts of the biological control agents in each state (Coulson 1977).**

PURPOSE AND OBJECTIVES

The purpose of the current study was to re-examine the impact of the biocontrol insects on alligatorweed 10 years after the last review (Coulson 1977). Objectives were as follows:

a. Estimate the current acreages of alligatorweed by state.

b. Determine methods used by each state for controlling alligatorweed.

c. Describe the effectiveness of the biological agents in controlling alligatorweed in each state.

---

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

** Coulson 1977. "Biological Control of Alligatorweed, 1954-1972: A Review and Evaluation." Technical Bulletin No. 1547, U.S. Department of Agriculture, Washington, D.C.

METHODS

A questionnaire and a field survey were used to determine the extent of the alligatorweed problem and the impact the insects were producing. The questionnaire was sent to state and Federal agencies who conduct aquatic weed control, in order to obtain current and historical information about alligatorweed and the biocontrol insects in each area. A field survey of 10 states was conducted twice during the growing season (June 1982 and October 1982). More than 50 states (Figure 1) were selected to be monitored with additional sites being added during the initial survey.

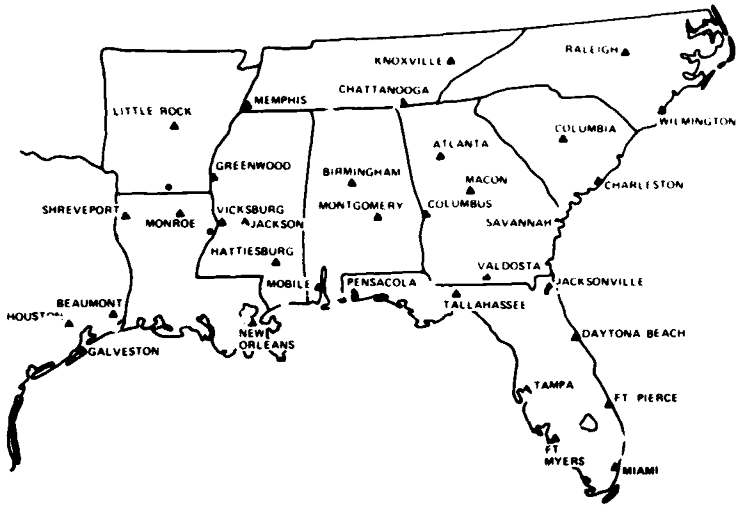


Figure 1. Alligatorweed sampling sites

RESULTS AND DISCUSSION

Alligatorweed was found in nine of the ten states visited during the field survey and a regional pattern of its distribution was noticed. Information will be presented according to the regional pattern with states having similar results being presented together.

Gulf coast states (Florida, Louisiana, Mississippi, and south Alabama). Alligatorweed problems in Florida, Louisiana, Mississippi, and south Alabama are being controlled primarily by the flea beetle and the stem borer. All three biocontrol insects are present in Florida and they are producing excellent control. Mississippi and south Alabama have minimal problems with alligatorweed. A few locally serious problems do develop, but the biocontrol insects, especially the flea beetle and the stem borer, have greatly reduced these occurrences. Louisiana reports the largest acreage of alligatorweed of any state surveyed but indicates that their problem is usually only locally serious. Since more than one third of the alligatorweed found in Louisiana is terrestrial, it is not severely impacted by the flea beetle or the stem borer and is not considered to be a problem that necessitates control by Louisiana officials.

Atlantic coast states (Georgia, South Carolina, and North Carolina). Varying degrees of insect control were observed throughout Georgia, South Carolina, and North Carolina. Georgia has the smallest alligatorweed problem of any of these states. The flea beetle and stem borer have contributed greatly to the alligatorweed control in Georgia. South Carolina had 30,000 acres of alligatorweed in 1963; today this has been reduced to 1,000 acres. The current problem areas in South Carolina are hard to control because much of the alligatorweed is in the terrestrial form for part of the year. The stem borer and the flea beetle prefer and, in fact, require the aquatic form of alligatorweed to exist; therefore, their impact is limited by the occurrence of the terrestrial form. North Carolina is the northern range for alligatorweed problems. The impact of the flea beetle is limited because the beetle does not tolerate cold conditions. The stem borer can withstand the cold, but its population does not build to adequate levels for control until late in the growing season. Biological control of alligatorweed with insects in North Carolina is limited unless the insect populations are managed to ensure that individuals are present earlier in the growing season.

Northern states (Tennessee, north Alabama, and Arkansas). Tennessee, north Alabama, and Arkansas generally have isolated problem areas of alligatorweed. Tennessee Valley Authority officials indicate that alligatorweed occurs only as small isolated mats in Tennessee. No alligatorweed was found in Tennessee during either of the field surveys. The alligatorweed problems present in northern Alabama are being treated by a management plan using biocontrol agents. For the last 3 years, early releases of the flea beetle into problem areas have produced excellent results. The alligatorweed problems observed in Arkansas appear to be locally serious but no management program is being conducted to reduce the problem. Biocontrol insects do migrate into Arkansas late in the growing season, but their impact is minimal.

Southwestern state (Texas). Alligatorweed is found along the eastern border and in the gulf coast area of Texas. Alligatorweed grows well in Texas, but the biocontrol insects are subjected to extreme environmental factors, such as flooding or droughts. These environmental factors greatly impact the insect population but usually have little impact on the alligatorweed population. Unless the insects are managed, their population will be reduced so severely that a long period of time will be required to reestablish effective levels.

CONCLUSIONS

The biocontrol agents are significantly impacting alligatorweed throughout the states surveyed. In states such as North Carolina or Texas, management plans would greatly increase the effectiveness of the insects. These biocontrol insects which impact alligatorweed are tools for controlling alligatorweed and need to be monitored and managed to achieve their maximum effectiveness.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

An Overview

by
Howard E. Westerdahl*

Research conducted under the Chemical Control Technology Development element of the Aquatic Plant Control Research Program (APCRP) is directed toward accelerating the development and use of new herbicide formulations and improved application techniques. Specifically, work is ongoing to determine target and nontarget aquatic macrophyte effects resulting from herbicide applications on previously stressed aquatic macrophytes, i.e. nutrient-poor sediment and water, time of year, and variable water temperature. Completion of research will result in identification of environmentally compatible herbicides and appropriate techniques for their safe and effective application.

Three work units were identified for FY 1984 that address specific needs within this APCRP element, including:

I: Herbicide Evaluation Program

II: Controlled-Release Fluridone for Aquatic Plant Control

III: Herbicide/Adjuvant Evaluation in Flowing Water

Two previous work units entitled "Controlled-Release Dichlobenil for Aquatic Plant Control" and "Aquatic Herbicide User Guide" were terminated in FY 1983 prior to completion. It was decided that, until potable water tolerances were established for dichlobenil, further evaluation should be postponed. The development of a herbicide user guide was postponed indefinitely based on recommendations by CE District representatives at the APCRP review following the 17th Annual APCRP Meeting. A proposed outline of a herbicide user guide was prepared following a national workshop at WES and review comments were provided by District and project office personnel.

The objectives of Work Unit I are to develop, evaluate, and seek registration for controlled-release (CR) herbicides; cooperate with chemical companies in developing and testing new herbicides and formulations for aquatic use; determine threshold herbicide concentrations required to control aquatic macrophytes; and coordinate in-house herbicide tests with supported ongoing research at the U.S. Department of Agriculture (USDA) Aquatic Plant Management Laboratory (APML) in Fort Lauderdale, Fla. Mr. Jerry Hall, WES, will discuss work during FY 1983 concerning the determination of threshold herbicide concentrations and Dr. Thai Van will summarize ongoing activities at the USDA-APML.

Activities in FY 1984 and 1985 include: identification of herbicide concentration/exposure time relationships for fluridone; continued cooperation with USDA-APML; determination of threshold herbicide concentrations for registered aquatic

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

herbicides; field evaluation of CR Poly-GMA 2,4-D and CR PCL fluridone pellets; and identification of the important physiological and environmental factors influencing efficacy of aquatic herbicides.

Dr. Richard Dunn, Southern Research Institute (SRI), will discuss work during FY 1983 and plans for FY 1984 concerning the development of CR PCL fluridone pellets relating to Work Unit II. The objective of Work Unit II is to develop and evaluate a CR fluridone formulation. During FY 1984, efforts will be focused on developing a pelletized formulation of the CR PCL fluridone fiber formulation. Laboratory and field evaluations of the CR pellets will be initiated during FY 1984. This CR formulation has been adequately developed to warrant SRI initiating the steps necessary to obtain Federal registration and marketing of this CR formulation, thus eliminating the need for CE involvement during FY 1985.

Activities in Work Unit III will be described by Dr. Kurt Getsinger, WES. Briefly, the objectives of this research are to compare selected conventional herbicides and herbicides/adjuvant mixtures in flowing water, and evaluate the effectiveness of CR herbicides in flowing water.

During FY 1984, efforts will continu to determine which 2,4-D/adjuvant mixtures have potential for controlling aquatic macrophytes in flowing water. Other herbicide/adjuvant mixtures will be tested to compare with the results of the 2,4-D/adjuvant tests. If herbicide release from the herbicide/adjuvant mixture is independent of herbicide, the testing may be terminated and appropriate guidance provided to the Districts. This latter evaluation and initiation of CR formulation testing are planned for FY 1985.

Finally, Dr. Frank Harris, University of Akron, will discuss the progress of his research involving pilot plant scale-up to provide field test quantities of the CR formulation Poly GMA/2,4-D. Sufficient test quantities will be available in FY 1985 to evaluate this CR formulation at several Corps reservoirs and waterways. Preliminary testing at the USDA-APML suggests this CR formulation to be very predictable in releasing 2,4-D to the water.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

The Use of Controlled Release Fluridone Fibers for Control of Hydrilla in Flowing Water

by
Thai K. Van* and Kerry K. Steward*

INTRODUCTION

Fluridone (1-methyl-3-phenyl-5-[3(trifluoromethyl)phenyl]-4(1H)-pyridinone), a new preemergence herbicide for use on cotton (Waldrep and Taylor 1976), has proven effective for controlling hydrilla (*Hydrilla verticillata* L. F. Royle) and several other submersed aquatic vascular plants in relatively lentic habitats (Arnold 1979). However treatments with fluridone in flowing water have provided poor hydrilla control, probably because the herbicide disperses away from application sites before the necessary herbicide-plant contact time may be achieved. This paper reports the progress of our cooperative efforts with the Corps in developing various controlled release (CR) herbicide formulations of fluridone for use in the management of submersed aquatic plants in flowing water.

MATERIALS AND METHODS

Chemicals

The various monolithic fibers of fluridone (25 percent a.i.) were provided by the Southern Research Institute, Birmingham, Ala. The herbicide fluridone was incorporated into fibers prepared from polycaprolactone, a biodegradable polymer. The fibers were designed to entangle with submersed vegetaion and thus not be carried downstream in flowing water applications. The monolithic fibers were made to different filament diameters in order to achieve different herbicide release rates.

The Black Charm (BC) pellet formulation (5 percent a.i.) and the liquid Sonar® 4AS (4 lb a.i. per gallon) were obtained from Elanco, Indianapolis, Ind. The BC pellets sink to the bottom muds and release the herbicide near the soil-water interface where plant growth originates and where propagating structures are located.

Determination of time-course uptake

Apical sections of hydrilla 15 cm long were collected from Lake Okeechobee, Florida. The plants were cultured for 7 days under controlled environment conditions (0.05-strength Hoagland, 27°C, 14-hr photoperiod, 1000 $\mu E/m^2/sec$). After this initial growth period, the top 4-cm sections were excised under water, and uniform sections were selected for the experiment.

---

* Aquatic Plant Management Laboratory, U.S. Department of Agriculture, Fort Lauderdale, Florida.

One 4-cm plant section was planted in each test tube (2.5 cm diameter and 15 cm long), containing 40 ml of diquat-^{14}C solution (a total of 2.0×10^{-2} μCi giving a diquat cation concentration of 0.10 mg/ℓ) or fluridone-^{14}C (a total of 1.7×10^{-2} μCi giving 0.05 mg/ℓ fluridone). Each treatment was replicated three times.

After different exposure periods (from 2 hr to 21 days) the treated plant sections were removed from the test tubes; rinsed for two 1-min periods in technical, nonlabeled herbicide at the same concentration as the labeled solution, and then rinsed another 2 min in running tap water. The plant sections were then freeze dried and combusted for liquid scintillation counting.

Response of hydrilla to various concentrations and exposure periods of fluridone

Apical sections of hydrilla 15 cm long were planted in small plastic pots filled with a standard soil mix (70 percent sand and 30 percent organic peat), and 16 of these pots were placed in each aquarium containing 19 ℓ of pond water. The plants were allowed to become established for a period of 2 weeks. Water in the aquaria was replaced every 3 days.

The liquid Sonar 4AS was applied to the aquaria at concentrations of 0.05, 0.10, 0.25, and 0.50 mg/ℓ fluridone. Tests at all concentrations were replicated three times. Each of the four treatment rates of fluridone was in contact with the plants for periods of 3, 6, 12, 24, 48, 96, and 168 hr. After each exposure period, the plants were removed from the treatment aquaria and placed in a running bath of pond water for 30 min to remove any adhering herbicide. Then two pots from each aquarium were placed in a 4-ℓ glass jar containing fresh pond water. These jars were placed in a glass greenhouse, and phytotoxic responses were observed during a period of 14 weeks.

Static water test to determine release profiles

Herbicide release profiles in static water were determined under controlled laboratory conditions at 28 ± 2°C. Treatments of various CR formulations were made to 3.7 ℓ of water with amounts calculated to produce 10 mg/ℓ available fluridone assuming complete release. Treatments were replicated four times.

Natural water from a dug pond on the Fort Lauderdale Agricultural Research Center grounds was used. Water quality was monitored monthly. For inter-laboratory comparisons, release profiles were also determined in reconstituted distilled water at pH 8.0, containing 192 mg $NaHCO_3$, 120 mg $CaSO_4 \cdot 2H_2O$, 120 mg $MgSO_4$, and 9 mg KCl per litre (Marking and Dawson 1973). Water samples were taken from each container at various times throughout the experiment for fluridone determinations. At the conclusion of the study, the formulations were collected and extracted in methanol (3 × 100 ml) for 24 hr. Extracts were analyzed to determine the amount of fluridone that had remained incorporated in the different formulation matrices.

Flowing water test and bioassay of hydrilla

Natural pond water was continuously pumped into a system of 24 outdoor aquaria. The dimensions of the aquaria were 77 cm wide by 219 cm long (1.7×10^{-4} ha) with depth varying from 50 to 56 cm. The normal volume of these containers after adding soil was 850 to 950 ℓ. Uniform low water pressure was maintained by constant overflow in a standpipe, and flow to individual aquaria was regulated by small petcock valves to provide one volume change every 24 hr. The outflow water was collected at 25 cm below surface and passed through a charcoal filter before discharge.

Hydrilla plants were established in 30- × 30-cm-square aluminum trays, 15 cm deep. Six trays were placed in each culture aquaria and allowed to grow for 6 months before chemical treatment was applied. All fluridone formulations were applied at 2.2 kg a.i./ha on 31 August 1983. Herbicides residues in the flowing water were determined at various times during the experiment, and phytotoxic responses to the herbicide treatments were recorded.

Herbicide analyses

Fluridone determinations were made on a Perkin Elmer series 3B liquid chromatograph equipped with an absorbance LC75 detector operated at 236 nm. The chromatographic conditions were as follows: column, HS-5 C_{18} reversed phase; mobile phase, acetonitrile:1 percent acetic acid (1:1 v/v); flow rate, 2.0 ml/min; internal standard, 2,4-dichlorophenoxy acetic acid.

RESULTS AND DISCUSSION

The uptake of ^{14}C from ^{14}C-diquat or ^{14}C-fluridone by hydrilla during a 21-day period is presented in Figure 1. Diquat was taken up rapidly and a maximum tissue level of ^{14}C was observed within 4 days after treatment. The plants began to decompose after 7 days. The decline in radioactivity in the plant tissues during the second week after treatment was probably due to leaching and/or breakdown of the ^{14}C from the decaying plant tissues.

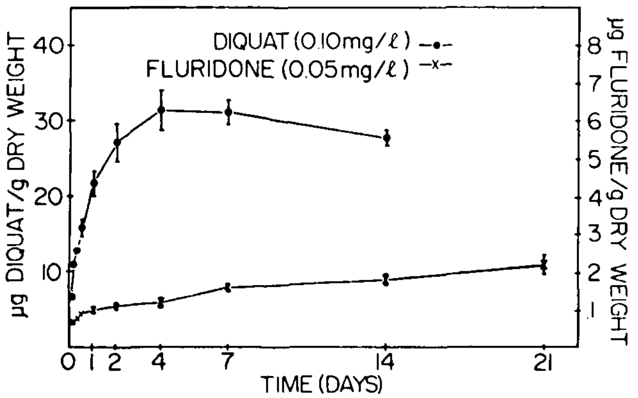


Figure 1. Uptake of ^{14}C-diquat and ^{14}C-fluridone by hydrilla. Bars indicate ± standard error for each time interval

A much slower uptake rate was obtained with the ^{14}C-fluridone treatment (Figure 1). The initial rise in radioactivity in hydrilla tissues observed at the first sampling 2 hr after treatment probably represents the passive diffusion and/or adsorption of ^{14}C-fluridone in intercellular free space. The slower, long-term phase of uptake was probably due to metabolic accumulation which appeared to continue at a fairly constant rate for at least 21 days.

The data presented for the uptake of fluridone suggested that the herbicide must remain in contact with the plant for a comparatively long time before herbicide concentration is present in the plant tissues at levels sufficient to achieve weed control. Table 1 presents the response of hydrilla to various concentrations and exposure periods of fluridone. Over 90 percent control of hydrilla was observed in all treatments from 0.05 to 0.50 mg/ℓ of fluridone, when the plants were exposed to

Table 1
Response of Hydrilla to Various Concentrations and Exposure Periods of Fluridone under Greenhouse Conditions

Fluridone Treatment mg/ℓ	*Exposure Time hr*	*Percent Control at Weeks Posttreatment**							
		1	*2*	*4*	*6*	*8*	*10*	*12*	*14*
0.05	3	3	0	12	12	10	12	7	10
	6	0	0	8	8	12	17	18	28
	12	0	0	7	7	12	15	15	17
	24	10	0	10	10	20	20	20	20
	48	10	0	10	10	20	20	17	25
	96	17	10	5	10	17	22	25	28
	168	10	10	10	20	33	28	40	43
	2352**	13	20	17	17	48	65	95	95
0.10	3	0	3	12	12	12	12	10	22
	6	3	3	8	8	18	18	17	32
	12	10	3	10	10	12	13	8	10
	24	13	3	10	10	20	20	20	33
	48	17	3	8	8	22	22	20	32
	96	18	13	15	18	45	43	50	60
	168	17	15	10	18	37	45	42	38
	2352**	13	17	10	10	55	68	93	87
0.25	3	0	3	13	12	17	15	10	12
	6	0	5	10	10	20	25	37	45
	12	10	5	10	18	23	25	22	18
	24	13	3	17	17	38	43	45	48
	48	22	7	22	22	55	75	75	63
	96	20	15	20	23	72	72	77	82
	168	13	12	17	17	53	70	82	92
	2352**	13	13	18	20	59	72	90	90
0.50	3	0	10	18	12	20	25	18	23
	6	0	5	10	13	15	25	30	43
	12	13	10	18	18	23	50	47	40
	24	18	7	20	20	48	63	68	73
	48	20	17	22	27	67	85	77	75
	96	18	13	23	28	32	85	92	93
	168	10	10	20	20	33	90	90	95
	2352**	10	17	17	20	67	80	95	95
Control	0	0	0	0	0	0	3	3	3

* Average of three replicates.

** Continuous exposure of the plants to the chemical treatment throughout the 14-week experiment.

the chemical continuously throughout the 14-week experiment. However, no significant plant injury was obtained by exposing hydrilla plants up to 1 week to a concentration of 0.10 mg/ℓ fluridone. The 0.10-mg/ℓ fluridone treatment would be equivalent to a field treatment rate of 2 lb a.i./acre to a body of water 6 to 7 ft deep. Increasing the treatment levels of fluridone to 0.25 or 0.50 mg/ℓ resulted in effective hydrilla control with required exposure periods of 7 and 14 days, respectively (Table 1). However, these treatment levels may become cost-prohibitive in practical hydrilla control.

The slow uptake of fluridone and the long exposure time to this herbicide may present a problem in the control of hydrilla with fluridone in flowing water, such as in irrigation and drainage canals. One logical approach to this problem would be to incorporate the chemical in a CR formulation. The CR formulation would be designed to provide adequate plant contact through timed release of the herbicide, thereby increasing the chances for plant intake.

Herbicide release profiles were constructed for the release of fluridone from the monolithic fibers and the BC pellets into reconstituted water (Figure 2) and natural pond water (Figure 3). Release of fluridone from all of the formulations tested was first-order as expected. The BC pellets released over 60 percent of its fluridone within the first 3 days after treatment in reconstituted water. Herbicide release then slowed down gradually, and was complete in about 10 days. Furthermore, only 70 to 80 percent of the available fluridone was released from the BC pellets in natural pond water and in reconstituted water.

For the CR fibers, release rates appeared to depend on the different fiber sizes, with the thinner fibers releasing herbicide at much faster rates. For the 8-mil fiber, most of the release was completed in about 10 to 15 days. On the other hand, herbicide release continued over a period of 40 to 50 days in the 30-mil and 45-mil fibers. Only 65 to 80 percent of the available herbicide was released from the 30-mil and 45-mil fibers.

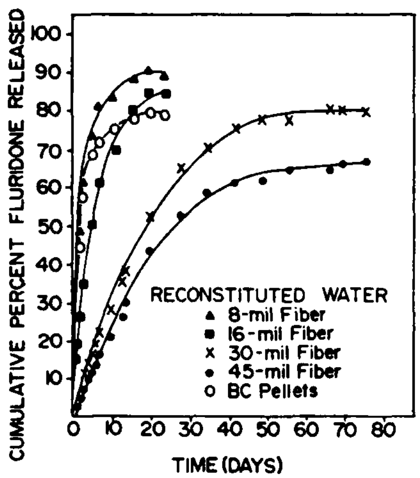


Figure 2. Cumulative percent release of fluridone from polycaprolactone monolithic fibers and BC pellets into reconstituted water

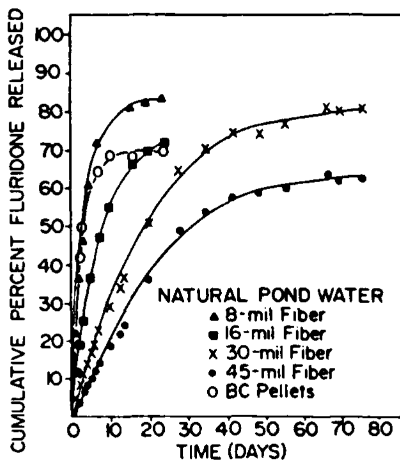


Figure 3. Cumulative percent release of fluridone from polycaprolactone monolithnic fibers and BC pellets into natural pond water

Study of the accountability of fluridone conducted at the termination of the experiment indicated that 12 and 23 percent of available fluridone still remained in the 30-mil and 45-mil fiber, respectively (Table 2). By adding up what had been released into water and what was left in the fibers, the total fluridone recovery was 90 percent or higher for all fiber sizes. Similarly, total recovery from BC pellets averaged 89 percent in reconstituted water and 90 percent in natural pond water.

The fluridone-loaded fibers and the BC pellets were evaluated for efficacy in controlling hydrilla in flowing water. The conventional liquid formulation Sonar 4AS was included for comparison. Table 3 shows herbicide residues in the flowing water from the Sonar 4AS treatment. A residue level of about 400 $\mu g/l$ fluridone was expected based on the water volume in the treatment tanks. However, the

Table 2
Accountability of Fluridone in Static Tests with Reconstituted Water and Natural Pond Water After 76 Days Posttreatment

	*Percent Fluridone Recovered**		
Treatment	*Water* %	*Fiber* %	*Total* %
BC pellets			
RCW**	79±1	10±1	89
NPW	72±1	18±1	90
8-mil fiber			
RCW	89±2	8±1	97
NPW	86±1	9±1	95
16-mil fiber			
RCW	88±1	6±1	94
NPW	82±2	11±1	93
30-mil fiber			
RCW	80±4	12±1	92
NPW	81±1	11±1	92
45-mil fiber			
RCW	67±2	23±1	90
NPW	63±1	27±1	90

* Means of four replicates ± S.E.

** RCW = reconstituted water; NPW = natural pond water.

Table 3
Fluridone Residue After Treatment with Sonar 4AS at 2.2 kg a.i./ha in Flowing Water in Outdoor Aquaria*

Tank Number	*Fluridone Residue (μ/l) at Days Posttreatment*					
	1/12	*1/4*	*1*	*2*	*7*	*14*
B4	801	569	104	31	BDL**	0
B6	995	678	73	26	BDL	0
B11	974	584	100	24	BDL	0
C2	1150	658	130	34	BDL	0
Average	980	622	102	29	BDL	0

* Aquaria 0.6 m deep with flowing water to provide one complete water exchange every 24 hr.

** BDL = less than 1 $\mu g/l$.

initial level of 980 $\mu g/l$ indicated that the herbicide was not evenly distributed over the entire water depth 2 hr after treatment. The herbicide concentrations then decreased rapidly to about 102 $\mu g/l$ fluridone after 1 day due to water flow, and then disappeared completely by day 7 posttreatment.

A concentration of 54 $\mu g/l$ fluridone was measured in treatment of the BC pellets 2 days after treatment (Table 4). The fluridone concentration then decreased sharply after 7 days, but was maintained at 3 to 5 $\mu g/l$ in the flowing water over a period of 3 weeks. The BC pellets had been found to complete most of herbicide release after about 10 days in water (Figure 3). In the flowing water test, however, hydrosoil may have acted as a second barrier to the herbicide release through soil adsorption and desorption. Also, a slower water flow near the soil-water interface may have contributed to the extended presence of the herbicide in flowing water in the BC pellet treatment.

In the CR fiber treatments, the herbicide concentrations in flowing water were low but maintained over a period of several days depending on the fiber sizes (Table 4). The 16-mil fiber treatment continued to release the chemical over a 2-week period, with a maximum level of 36 $\mu g/l$ fluridone measured on Day 7. For the 30-mil fibers, the measured herbicide levels were mostly below 14 $\mu g/l$ but maintained over 42 days. In the 45-mil fiber treatment, residue levels were all the time below 11 $\mu g/l$ but, again, lasted for 42 days.

Typical discoloration of the hydrilla tips was observed in all fluridone treatments 7 days after the chemical was applied. However, plants treated with the liquid Sonar 4AS appeared to recover rapidly while treatments of 30-mil and 45-mil fibers continued to show increased plant damage. Table 5 shows the effect of various fluridone formulations on chlorophyll content of hydrilla 6 weeks after treatment. The most severe chlorophyll damage was observed in plants treated with 30-mil and 45-mil fibers. The BC pellets reduced chlorophyll contents by 32 percent as compared to the level in control plants. The high chlorophyll contents in treatments of Sonar 4AS and 16-mil fiber reflected plant recovery from the herbicide 6 weeks after treatment.

Weed control by the various formulations of fluridone applied at 2.2 kg a.i./ha in flowing water in outdoor aquaria is presented in Table 6. The 30-mil and 45-mil monolithic fibers provided about 80 percent control of hydrilla 16 weeks posttreatment. Under the same conditions, the conventional liquid formulation Sonar 4AS was not effective.

REFERENCES

Arnold, W. R. 1979. "Fluridone - A New Aquatic Herbicide," *Journal of Aquatic Plant Management*, Vol 17, pp 30-33.

Marking, L. L., and Dawson, V. K. 1973. "Toxicity of Quinaldine Sulfate to Fish," *Invest. Fish Control*, No. 48, U.S. Fish Wildlife Service, Washington, D.C., pp 1-8.

Waldrep, T. W., and Taylor, H. M. 1976. "1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1H)-pyridinone, A New Herbicide," *Journal of Agriculture and Food Chemistry*, Vol 24, pp 1250-51.

Table 4

Fluridone Residue After Treatment with BC Pellets and Polycaprolactone Fibers at 2.2 kg a.i./ha in Flowing Water in Outdoor Aquaria*

Formulation		*Fluridone Residue (μg/l) at Days Posttreatment***							
		2	*7*	*14*	*21*	*28*	*35*	*42*	*49*
Pellets	BC	54±6	20±1	5±1	3±1	BDL†	0	0	0
Fibers	16-mil	32±6	36±2	5±1	BDL	0	0	0	0
Fibers	30-mil	13±2	14±2	9±1	8±2	4±1	3±1	2±1	BDL
Fibers	45-mil	10±1	11±2	7±1	6±1	4±1	3±1	3±1	BDL

* Aquaria 0.6 m deep with flowing water to provide one complete water exchange every 24 hr.

** Means of four replicates ± S.E.

† BDL = less than 1 μg/l.

Table 5

Chlorophyll Contents of Hydrilla Tips Treated with Various Formulations of Fluridone at 2.2 kg a.i./ha in Flowing Water in Outdoor Aquaria, 6 Weeks Posttreatment*

Formulation	*Total Chlorophyll*** *mg/g fresh weight*	*a/b Ratio*
Liquid 4AS	1.519[a]	2.24[a]
Pellets BC	0.972[b]	1.68[b]
Fibers 16-mil	1.373[a]	2.23[a]
Fibers 30-mil	0.424[c]	1.63[b]
Fibers 45-mil	0.443[c]	1.53[b]
Control	1.423[a]	2.39[a]

* Aquaria 0.6 m deep with flowing water to provide one complete water exchange every 24 hr.

** Values in a column followed by the same letter are not significantly different at the 5 percent level as determined by Duncan's Multiple Range Test. Each value is the mean of six replicates.

Table 6

Hydrilla Control by Various Formulations of Fluridone Applied at 2.2 kg a.i./ha in Flowing Water in Outdoor Aquaria*

Treatment	*Percent Control at Weeks Posttreatment***					
	2	*4*	*6*	*8*	*10*	*16*
Liquid 4AS	23	15	12	3	3	22
Pellets BC	26	25	38	48	42	52
Fibers 16-mil	21	24	35	15	10	15
Fibers 30-mil	19	40	45	59	72	84
Fibers 45-mil	25	36	50	55	63	78
Control	0	3	3	5	8	18

* Aquaria 0.6 m deep with flowing water to provide one complete water exchange every 24 hr.

** Average of four replicates.

AD-P003 607

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Determination of the Fluridone Concentration/Contact Time Relationship for the Control of *Myriophyllum spicatum* and *Hydrilla verticillata*

by
Jerry F. Hall*

INTRODUCTION

The relationship between herbicide concentration and exposure time is a concept which has received very little attention in regard to herbicides registered for use in the aquatic environment. Consequently, significant numbers of herbicide treatments each year provide little or no control of target aquatic macrophytes. Information concerning this herbicide concentration/contact time relationship would not only be beneficial for static water applications, but absolutely required for flowing water treatment of aquatic macrophyte infestations. The greatest benefit however is that developers of conventional and controlled-release herbicide formulations would have much clearer guidance for identifying treatment and release rates. The objective of this study was to determine the effective fluridone concentration and contact time required to control *Myriophyllum spicatum* (Eurasian watermilfoil) and *Hydrilla verticillata* (hydrilla).

MATERIALS AND METHODS

A diluter system (Westerdahl and Hall 1983) was modified to permit delivery of two constant-rate concentrations of fluridone for five different exposure periods. The fluridone concentrations/contact times selected were 4.0 $\mu g/l$ for 0.5, 1, 12, and 40 days and 9.0 $\mu g/l$ for 0.5, 1, 12, and 20 days. These concentrations and exposure times were selected so that treatment and release rates of an experimental controlled-release formulation having a 15- or 30-day release profile could be evaluated. Following exposure of an aquarium to a given fluridone concentration for a designated contact time, only reconstituted natural hard water (U.S. Environmental Protection Agency 1975) was permitted to flow through the aquarium for the remainder of the study. One reference set of aquaria containing the target macrophytes received only reconstituted hard water throughout the study period.

Approximately 4 weeks prior to testing, four 15-cm meristematic cuttings of watermilfoil were planted in each 250-ml glass beaker by burying the cut end of the plants approximately 5 cm in the substrate. Sand was placed over the substrate to an approximate depth of 2 cm to prevent the substrate from mixing with the overlying water during handling. The substrate was a natural, fine-textured sediment obtained from Brown's Lake at the U.S. Army Engineer Waterways

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Experiment Station. The same procedure was followed using meristematic cuttings of hydrilla. Six beakers containing watermilfoil and three beakers containing hydrilla were placed in each aquaria. During the 4 weeks prior to testing, only the reconstituted natural hard water flowed through the aquaria to allow root development from the plant cuttings.

Water samples for fluridone analysis were obtained at 4 and 8 hr following initiation of herbicide flow through those aquaria designated to receive the 12-hr exposure period. Water samples from the remaining aquaria were collected 1, 3, 7, 13, 28, and 36 days following the initial exposure of these aquaria to fluridone.

At the end of 15 weeks, the plants were removed from each beaker by washing the substrate with deionized water. Shoots and leaves of watermilfoil and hydrilla were subsampled from each aquarium, representing each herbicide concentration and contact time. Plant tissues were extracted to clarity in vials containing 20 ml of dimethylsulphoxide (DMSO) in accordance with the procedures of Hiscox and Israelstam (1980). All chlorophyll determinations were made on a Beckman Model 26 spectrophotometer and chlorophyll *a* and *b* concentrations were calculated as described in the literature (Arnon 1949). The remaining plants within each beaker were separated into roots and shoots, dried at 80°C for 24 hr, and weighed (accuracy $\pm$ 0.5 mg).

The effects of the two fluridone concentrations and the five contact times on the growth of watermilfoil and hydrilla were determined using percent plant injury (0 = no control, 100 = total kill) and a set of qualitative factors currently in use at the Aquatic Plant Management Laboratory in Fort Lauderdale, Fla. (Hoeppel and Westerdahl 1981). The qualitative factors include: heavy algal cover; roots evident; absence of meristems on stems and branches; leaf loss; evidence of solarization; stem flaccidity; degree of node or internode decomposition; stem and branch tip decomposition; general decomposition of plants; advanced decomposition (only a few stems remaining intact); complete disintegration of plant material; and subsequent regrowth. Duncan's Multiple Range Test was used to make comparisons among shoot and root biomass means and chlorophyll *a* and *b* means at each fluridone concentration and contact time. The more conservative Dunnett's Test was used to compare all experimental shoot and root biomass means and chlorophyll *a* and *b* concentration means with the reference means. All statements of significance refer to the 5-percent level of statistical confidence.

RESULTS AND DISCUSSION

Periodic fluridone analysis of the inflow water to each aquarium permitted evaluation of the fluridone concentration passing into the aquaria. The mean fluridone concentrations flowing into the aquaria were 4.0 ± 0.10 $\mu g/\ell$ or 9.0 ± 0.30 $\mu g/\ell$.

The effects of two fluridone concentrations and five contact times on shoot and root biomass of watermilfoil are seen in Table 1. Neither statistical test showed any significant reductions in watermilfoil shoot biomass following treatment with 4.0 or 9.0 $\mu g/\ell$ for the prescribed exposure times. Similarly, no statistically significant reductions in watermilfoil root biomass were observed following exposure to the two fluridone concentrations and five contact times. The effects of these fluridone

Table 1
Shoot and Root Biomass of Watermilfoil and Hydrilla Exposed to Two Fluridone Concentrations for Five Contact Times

Fluridone Concentration $\mu g/l$	*Contact Time, days*	*Mean Biomass, mg dry weight*	
		Watermilfoil	*Hydrilla*
		Shoots	
Reference	-	574 a	727 ab
4.0	0.5	586 a	786 a
4.0	1	517 a	762 ab
4.0	12	352 a	692 ab
4.0	40	519 a	367 b
Reference	-	574 a	727 a
9.0	0.5	601 a	784 a
9.0	1	486 a	628 ab
9.0	12	337 a	561 ab
9.0	20	278 a	371 a
		Roots	
Reference	-	223 a	62 a
4.0	0.5	222 a	50 a
4.0	1	200 a	55 a
4.0	12	226 a	55 a
4.0	40	226 a	60 a
Reference	-	223 a	62 a
9.0	0.5	257 a	45 a
9.0	1	201 a	55 a
9.0	12	233 a	35 a
9.0	20	183 a	50 a

Note: Values in a column followed by the same letter are not statistically different at the 5 percent level as determined by Duncan's Multiple Range Test.

* Statistically different from the reference at the 5 percent level as determined by Dunnett's Test.

concentrations and contact times on the chlorophyll content of watermilfoil are seen in Table 2. Neither chlorophyll *a* nor chlorophyll *b* concentrations were significantly reduced following herbicide exposure according to both Dunnett's and Duncan's tests. The plant injury ratings did not show any significant injury to watermilfoil as a result of exposure to fluridone. None of the typical symptoms of fluridone injury such as apical meristem discoloration or bleaching of leaves were observed in watermilfoil. The plants exhibited a healthy, robust appearance throughout the duration of the study.

The response of hydrilla root and shoot biomass to the fluridone concentrations and contact times is seen in Table 1. A significant reduction in shoot biomass was observed in hydrilla exposed to 9.0 $\mu g/l$ for 20 days. At this concentration/contact time, shoot biomass was reduced by 49 percent. However, this reduction was considered significant by only Duncan's Test. The more conservative Dunnett's Test did not consider this to be a significant reduction in hydrilla shoot biomass. No significant reductions in hydrilla root biomass were observed at either of the fluridone concentrations.

Table 2
Chlorophyll *a* and *b* Content for Watermilfoil and Hydrilla Exposed to Two Fluridone Concentrations for Five Contact Times

Fluridone Concentration $\mu g/l$	*Contact Time, days*	*Mean Chlorophyll Content, $\mu g/g$ fresh tissue*	
		Watermilfoil	*Hydrilla*
		Chlorophyll *a*	
Reference	-	570 a	310 ± 10 a
4.0	0.5	580 a	270 ± 10 ab
4.0	1	620 a	270 ± 4 ab
4.0	12	480 a	360 ± 4 a
4.0	40	460 a	210 ± 40 b
Reference	-	570 a	310 a
9.0	0.5	540 a	360 a
9.0	1	600 a	320 a
9.0	12	480 a	320 a
9.0	20	730 a	340 a
		Chlorophyll *b*	
Reference	-	210 a	100 a
4.0	0.5	250 a	80 a
4.0	1	220 a	80 a
4.0	12	160 a	100 a
4.0	40	180 a	90 a
Reference	-	210 a	100 a
9.0	0.5	140 a	100 a
9.0	1	250 a	70 a
9.0	12	220 a	80 a
9.0	20	270 a	110 a

Note: Values in a column followed by the same letter are not statistically different at the 5 percent level as determined by Duncan's Multiple Range Test.

* Statistically different from the reference at the 5 percent level as determined by Dunnett's Test.

The effects of the fluridone concentrations and contact times on the chlorophyll content of hydrilla are also seen in Table 2. A 30-percent reduction in chlorophyll *a* content was observed in hydrilla exposed to 4.0 $\mu g/l$ fluridone for 40 days. However, this reduction was considered significant by only Duncan's Test. The more conservative Dunnett's Test did not recognize this as a significant reduction. No significant reductions in chlorophyll *b* content were observed in hydrilla.

The plant injury ratings did not show any significant injury to hydrilla following exposure to the fluridone concentrations. Some stem discoloration and leaf bleaching were observed in hydrilla exposed to 4.0 $\mu g/l$ for 12 and 40 days and to 9.0 $\mu g/l$ for 12 and 20 days. However, these symptoms disappeared following termination of herbicide exposure and the plants regained a healthy, robust appearance for the remainder of the study.

CONCLUSIONS AND RECOMMENDATIONS

These data indicate that 4.0 μg/ℓ fluridone for 0.5, 1, 12, and 40 days or 9.0 μg/ℓ fluridone for 0.5, 1, 12, and 20 days are not efficacious for the control of watermilfoil and hydrilla. Fluridone at these concentrations and contact times does not significantly affect biomass production or chlorophyll content in these aquatic macrophytes. This study should be repeated using higher fluridone concentrations, e.g. 15.0 and 30.0 μg/ℓ, and similar exposure periods in order to better understand the relationship between concentrations and contact time.

REFERENCES

Arnon, D. I. 1949. "Copper Enzymes in Isolated Chloroplasts; Polyphenoloxidases in *Beta vulgaris*," *Plant Physiology*, Vol 24, pp 1-5.

Hiscox, J. D., and Israelstam, G. F. 1980. "A Method for the Extraction of Chlorophyll from Leaf Tissue Without Maceration," *Canadian Journal of Botany*, Vol 57, pp 1332-1334.

Hoeppel, R. E., and Westerdahl, H. E. 1981. "Herbicide Evaluation Program," Aquatic Plant Control Research Program Information Exchange Bulletin, Vol A-81-1, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

U.S. Environmental Protection Agency. 1975. "Methods for Acute Toxicity Tests with Fish, Macroinvertebrates, and Amphibians," EPA-660/3-75-009, Washington, D.C.

Westerdahl, H. E., and Hall, J. F. 1983. "The 2,4-D Threshold Concentrations to Control Eurasian Watermilfoil and Sago Pondweed," *Journal of the Aquatic Plant Management Society*, Vol 21, pp 22-25.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Herbicide/Adjuvant Evaluation in Flowing Water

by
Kurt D. Getsinger*

INTRODUCTION

The invasion of nuisance, submersed aquatic plants into rivers, streams, and canals, particularly in the Pacific Northwest, has prompted interest in the management of these plants in flowing water. One approach to the management of submersed weeds in flowing water is through the use of chemical herbicides and herbicide/adjuvant mixtures. Adjuvants are designed to increase the effectiveness of conventional herbicide formulations. Examples of such materials are surfactants, wetting agents, oils, stickers, spreaders, thickening agents, emulsifiers, etc.

For a herbicide to be effective, a minimum concentration of that herbicide must be maintained near the target plant, either in the sediment or water column, for some minimum contact time. This presents a problem in flowing water since the water column is continuously moving and herbicides released into the water are transported downstream. Herbicide/adjuvant mixtures have been used effectively for control of submersed plants in static water environments; however, limited data are available on their use in flowing water. A primary concern is the length of time adjuvants can hold herbicides in the vicinity of the target plant when exposed to various flow velocities.

OBJECTIVES

The herbicide/adjuvant evaluation study at WES is designed to determine which herbicide/adjuvant mixtures show potential in controlling submersed weeds in flowing water and to compare these mixtures with conventional herbicide formulations. Initial studies will deal with the application of various 2,4-D adjuvant mixtures on the submersed species Eurasian watermilfoil (*Myriophyllum spicatum* L.). Eurasian watermilfoil was selected as the target plant because it is rapidly spreading throughout flowing water systems in the West and Northwest. The herbicide 2,4-D was selected because of its proven efficacy on Eurasian watermilfoil. Adjuvants used in the initial phases of the study will include the inverting oils/emulsions Asgrow 403, Bivert, and I'vod and the polymers, Polycontrol and Nalquatic.

MATERIALS AND METHODS

Herbicide/adjuvant experiments were conducted in a hydraulic flume at WES. A schematic of the flume system is shown in Figure 1. A 30-m section of the flume

---

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

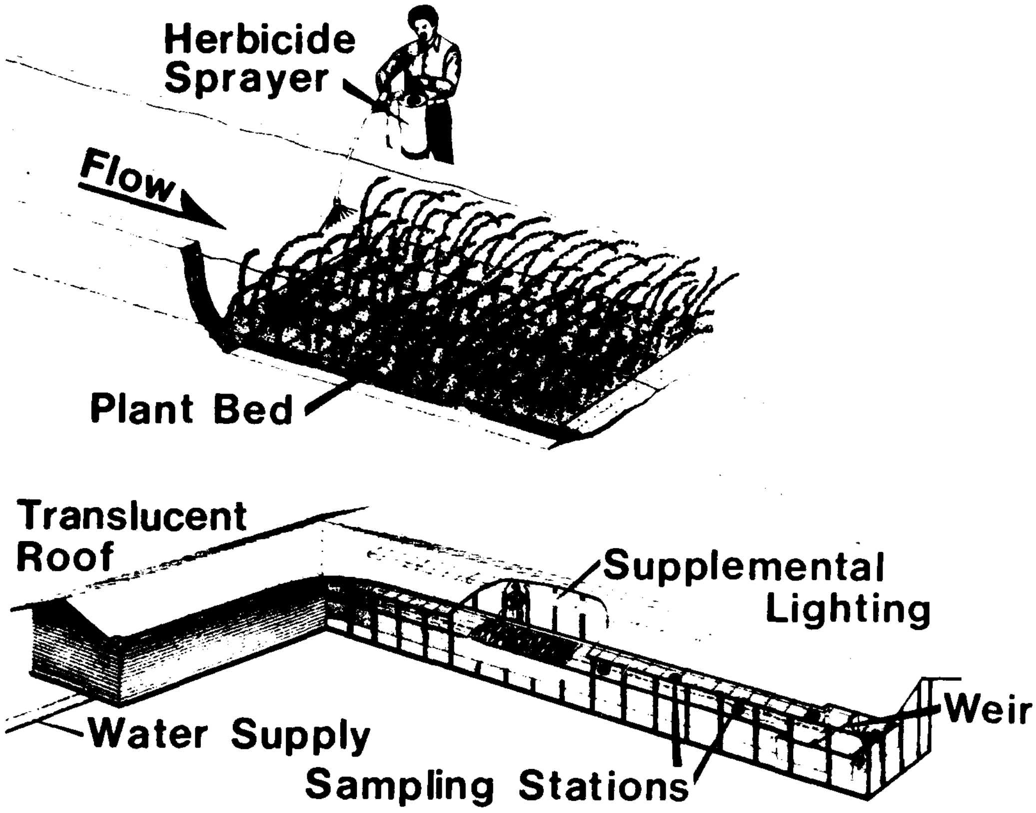


Figure 1. Flume system set up to evaluate the effectiveness of herbicide/adjuvant mixtures in controlling aquatic plants growing in flowing water

channel was divided into two equal sides (80 cm wide × 90 cm deep) to accommodate duplicate experiments (Figure 2). Individual plant shoots, collected in the field, were cut into 60- to 70-cm lengths and planted in shallow polyethlene basins (23 cm wide × 32 cm long × 10 cm deep) filled with a sand/mud mixture. These basins were arranged along the bottom of the flume (27 basins per channel) to produce two plant stands, 3 m in length, consisting of over 1600 shoots each. The plant stands approximated field densities. Greenhouse roof panels (90 percent transmittance) covered the plants from above and supplemental lighting was available, if needed.

The first herbicide/adjuvant formulation to be evaluated was an invert emulsion consisting of an inverting oil (Asgrow 403), 2,4-D DMA (Weedar 64), and water. This formulation was compared with a liquid formulation of 2,4-D DMA (Weedar 64), a pelletized formulation of 2,4-D BEE (Aqua-Kleen), and a noninvert mixture (Asgrow 403, 2,4-D DMA, and water). All formulations were prepared to give a 2,4-D treatment rate of 45 kg acid equivalent (a.e.)/ha.

Both the invert emulsion and the noninvert mixture consisted of a ratio of 7 parts water to 1 part inverting oil and were prepared using a Minnesota Wanner (MW) Invert Pump Pak designed for aquatic spraying. The principal components of this system included a Briggs & Straton 11-hp engine, a Wanner 10-gpm positive displacement piston pump, and a MW mechanical inverter.

Figure 2. Flume channel divided into two equal areas

The invert emulsion and noninvert mixture were prepared using the MW Pump Pak and captured in a 19-ℓ plastic bucket. The formulations were transferred to a 7.6-ℓ pressurized paint pot and sprayed below the surface onto the plant beds at 1.36 atm with a hand-held, fan-jet wand. The liquid 2,4-D DMA formulation was also applied on the plants using the paint pot system. The pelletized 2,4-D BEE was sprinkled over the surface of the plant beds by hand.

When prepared correctly, an invert emulsion consists of water surrounded by oil and has a mayonnaiselike consistency. The herbicide is dissolved within the water phase of the emulsion. Inverts have the appearance of snow flakes when sprayed under the surface of the water and flakes of invert stick to leaves and stems of submersed plants. The quality of an invert is related to a number of mechanical and environmental factors. When using an MW Invert Pump Pak, the selection of appropriate metering orifices for water, herbicide, and inverting oil as well as maintaining adequate pressure and eliminating fitting and line air leaks are critical for blending a good invert. The quality of the water used in blending an invert emulsion may also affect the quality of the invert. A deficiency in any one of these factors can result in the production of a poor invert.

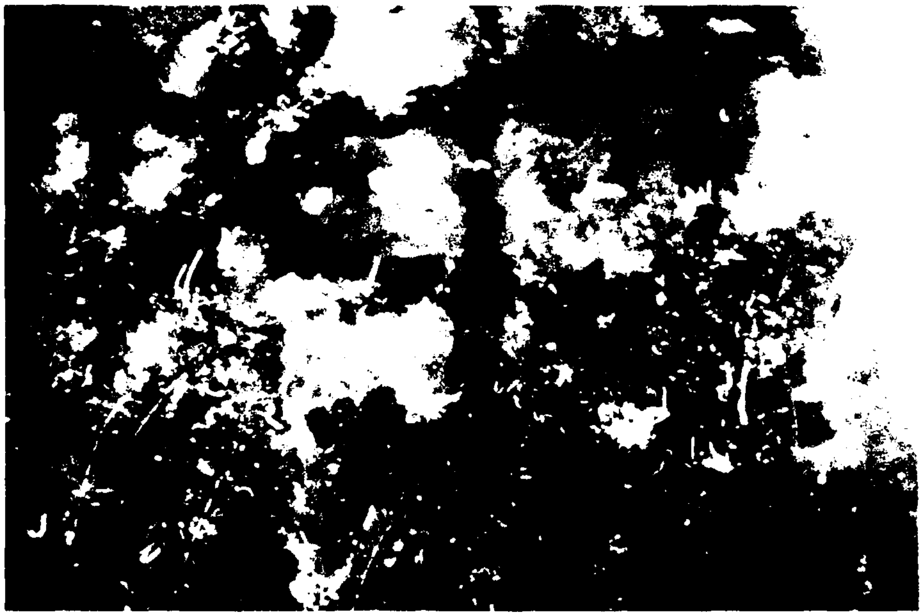


Figure 3. Flakes of invert emulsion clinging to submersed plants

A poor invert mixture has a thin, milky consistency (Figure 3), in contrast to the thick mayonnaiselike consistency of a desirable invert (Figure 4). Field applicators have implied that some confusion still exists concerning the consistency of a desirable invert emulsion. With that in mind, the invert emulsion and the noninvert mixture used in our experiments were prepared with identical water sources, herbicides, and calibrated equipment so that operator error, or inexperience, became the limiting factor in making a desirable invert emulsion.

Stream velocity was controlled at 3 cm/sec with a water depth of 76 cm. Each formulation was applied on duplicate plant beds. Mid-depth water samples were collected 5 m downstream from each plant bed at 2-min intervals posttreatment for 60 min. Samples were composited to represent 12-min periods and analyzed for 2,4-D residue. Water samples collected 5 m upstream from each plant bed during experimental runs showed no herbicide contamination.

PRELIMINARY RESULTS

Herbicide residue data (Figure 5) showed that the poor invert mixture and the liquid 2,4-D DMA formulation released 2,4-D into the water in a similar fashion. Both formulations released a large pulse of herbicide during the first 12 min, with herbicide residues below detection by 48 min posttreatment. In contrast, the good invert emulsion and the pelletized 2,4-D BEE formulation showed slower herbicide release rates, but herbicide residues still dropped below detection by 60 min posttreatment.

Figure 4. Milky consistency of a noninvert mixture

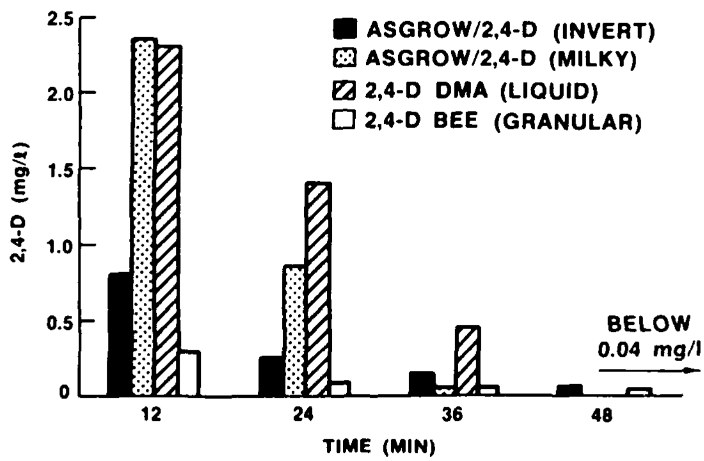


Figure 5. Effect of time on 2,4-D residues monitored 5 m downstream of plant beds

RECOMMENDATIONS

Preliminary data suggest that a poor invert mixture (Asgrow/2,4-D DMA) has no advantage over a liquid 2,4-D DMA formulation and that a good invert (Asgrow/2,4-D DMA) may not have an advantage over a pelletized 2,4-D BEE formulation when used in flowing water.

The recommendations suggested by this study include the following:

a. Experiments using Asgrow 403/2,4-D DMA and 2,4-D BEE should be repeated to monitor 2,4-D release for 3 hr posttreatment at velocities of 3, 6, 12, and 24 cm/sec.

b. Combinations of 2,4-D DMA with other adjuvants (I'vod, Bivert, Nalquatic, and Polycontrol) should be analyzed with respect to 2,4-D release rates in flowing water.

c. Herbicide concentration/exposure time studies should be initiated to evaluate the effectiveness of various release rates in flowing water.

ACKNOWLEDGEMENTS

The author would like to acknowledge Mr. Jerry Hall, Ms. Dawn Meeks, and Ms. Nancy Craft of WES for assistance in this study; Mr. Joe Zolczynski, Alabama Department of Conservation and Natural Resources, for field assistance; and the Laboratory Branch, Tennessee Valley Authority, for herbicide residue analysis. The author also wishes to thank Asgrow Florida Company and Union Carbide Agricultural for providing some of the chemicals used in this study.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Scale-Up Requirements for Controlled-Release Poly GMA-2,4-D

by
Frank W. Harris*

INTRODUCTION

The major goal of this research was to prepare and evaluate new polymers containing pendent herbicide substituents. These systems were to be designed so that herbicide release would occur by the slow, sequential hydrolysis of the herbicide-polymer chemical bonds. Over the past several years one polymer, Poly GMA, was found to release 2,4-D as designed.

POLY GMA DEVELOPMENT SUMMARY

Samples of Poly GMA with number average molecular weights (M_n) that ranged from 16,000 to 23,600 were prepared by carrying out the polymerization of glycidyl methacrylate (GMA) with different amounts of azokisisobutyronitrile (AIBN). The homopolymers were treated with various amounts of 2,4-D to yield a series of adducts that contained from 10 to 79 mole percent 2,4-D. These adducts, however, hydrolyzed very slowly when immersed in reconstituted hard water.

GMA was copolymerized with 2-hydroxyethyl methacrylate (HEMA), 2-hydroxyethyl acrylate (HEA), 2-hydroxypropyl methacrylate (HPMA), and 2-dimethylaminoethyl methacrylate (DMAEMA) to afford the corresponding copolymers, which were treated with 2,4-D. The 2,4-D/Copoly (GMA-HEMA) adducts hydrolyzed at nearly constant rates releasing 0.6 to 0.9 mg 2,4-D/g adduct/day. The adducts prepared from the HEA and HPMA copolymers hydrolyzed very slowly. A 2,4-D/Copoly (GMA-DMAEMA) adduct released 2,4-D at a rate of 5 mg/g copolymer/day.

The homopolymerization of GMA was carried out in the presence of various amounts of 2-mercaptoethanol (ME). The hydroxy-terminated homopolymers, which had M_n's of 5,800 and 8,600, were treated with 2,4-D to afford adducts that contained 60 mole percent of the herbicide. These adducts released 2,4-D at rates of 4.1 and 1.5 mg/g adduct/day, respectively. A similar homopolymerization of GMA in the presence of 1-propanethiol (PT) produced a polymer with an M_n of 5,300. An adduct of this polymer that contained 60 mole percent 2,4-D also underwent hydrolysis in reconstituted hard water releasing 2,4-D at a rate of 5 mg/g adduct/day.

Copolymerizations of GMA with HEMA were carried out in the presence of ME. The molar feed ratios of GMA to HEMA employed were 90:10 and 80:20. The

* Department of Chemistry, Wright State University, Dayton, Ohio.

copolymers were treated with 60 mole percent 2,4-D to afford adducts that released the herbicide at rates of 4.7 and 4.8 mg/g adduct/day, respectively.

2,4-D /Poly GMA adducts containing pendent glycol moieties were prepared by treating samples of Poly GMA with H_2SO_4 prior to their reaction with 2,4-D. Adducts obtained from Poly GMA with an M_n of 16,500 hydrolyzed slower than similar adducts that did not contain glycol groups. Adducts prepared from hydroxy-terminated Poly GMA samples with M_n's less than 6,000, however, released approximately 5 mg 2,4-D/g adduct/day.

The reaction of 2,4-D with GMA was scaled-up to provide kilogram quantities of HMOP 2,4-D. Large-scale polymerizations of the monomer in concentrated solutions, however, resulted in branched and cross-linked systems.

The synthesis of one of the most promising controlled-release systems prepared and evaluated in this study, i.e., an hydroxy-terminated, low-molecular-weight 2,4-D/Poly GMA adduct, was successively scaled-up to commercial levels. However, the processing of the adduct solution as obtained from the reaction mixture was difficult. A method must be developed to remove the solvent before the procedure can be used to prepare material for field tests.

AD-P003 609

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Pilot-Scale Production of Fibers for the Controlled Release of Fluridone

by
Richard L. Dunn,* John W. Gibson,*
Terry E. Lawler,* and W. Curtis Stoner, Jr.*

INTRODUCTION

It has been shown previously that aquatic herbicides such as diquat, manufactured by Chevron Chemical Company, and fluridone, marketed by Elanco, can be incorporated in polycaprolactone (PCL), a biodegradable polymer, and fabricated into fibers. In previous studies, the fibers gave a relatively constant release of the herbicide for various lengths of time depending upon the herbicide loading and fiber size. However, all of these fibrous delivery systems were tested only in the laboratory with 5 to 10 g of material. To determine whether the fibrous delivery systems would function in the field by entangling with the weeds and releasing herbicide at that site, larger quantities of the fibrous systems with short and long durations of herbicide release had to be prepared. The larger quantities of fibers could then be dispersed over 5-acre plots of weeds located in lakes, canals, and rivers with different flow rates of water. In this manner, the ability of the fibers to be dispersed in the field, their ability to entangle with the weeds in flowing water areas, and both the rate and duration of herbicide release required for effective weed control could be determined. Because the fluridone/PCL controlled-release fibers had been shown to be the most effective system on a laboratory scale, three field trials were scheduled during the summer of 1983 to determine the efficacy of this system on a large scale. The trial conditions were to be 2 lb of active fluridone/acre with release durations of 20 and 40 days.

EXPERIMENTAL

Materials

Fluridone, the aquatic herbicide used in all pilot-scale studies, was obtained from Elanco as a solid powder in a technical grade with purity levels ranging from 95 to 97.8 percent active ingredients for the various lots used. Polycaprolactone, the biodegradable polymer used as the fibrous matrix, was obtained as PCL 700 from Union Carbide Corporation. Several lots of PCL 700 with different melt-viscosity values were examined.

Preparation of fluridone/PCL blends

Several different methods of blending the fluridone with PCL were tried. The solution method consisted of dissolving the PCL in toluene, mixing the fluridone with the solution, evaporating the toluene, and finally cutting the thin sheets of

* Southern Research Institute, Birmingham, Alabama.

polymer and fluridone into small strips for melt spinning. In another procedure, the pellet/powder method, the pellets of PCL were dry blended with fluridone powder and then fed directly into the extruder. The last procedure, the powder/powder method, was to grind the normal PCL pellets to small particles similar in size to the fluridone, and dry blend the two powders which were then fed into the extruder. Because PCL melts at 65°C, the pellets had to be ground under cryogenic conditions to prevent melting of the polymer. This was achieved by grinding the PCL pellets on a laboratory Wiley mill with dry ice or commercially by Wedco, Inc. (Bloomsbury, N.J.).

Preparation of experimental fibers

Before we scaled up to the large melt extruder, we first prepared fluridone/PCL fibers with various fluridone concentrations and fiber diameters on a small ram extruder (50-g capacity) designed and built at the Institute. In these experiments, the fluridone/PCL blends were melt-spun at 90°C through a 20-mil-diam monofilament spinneret, cooled or quenched in ambient air, and then collected on a surface-driven winder located about 2 to 4 ft from the spinneret. The feed rates of the fluridone/PCL blends were about 0.2 g/min, and the fiber take-up speeds were 5 to 15 ft/min.

Preparation of fibers for field trials

To prepare the larger quantities of fluridone/PCL fibers needed for the field trials, we began our studies on pilot-plant equipment normally used for the production of continuous-filament yarns. This equipment consisted of a 0.75-in. melt extruder, air- or water-quench system, and a dual-godet take-up and Lessona winder.

Because the 0.75-in. extruder was unsatisfactory in producing the fluridone/PCL fibers with acceptable quality at reasonable production rates, we used the large 1-in. Killion extruder to make all of the fibers for the field trials. This extruder was equipped with a mixing screw (20:1 L/D), a model KMB-100 melt blender, and a 0.075-in.-diam monofilament die with a 12:1 L/D ratio. The extruded fiber passed through a 10-ft-long quench bath filled with water about 5° to 10°C, through guides, and over twin-godet take-up rolls. The fiber was collected on paper tubes on a Model 959 Leesona winder. The fiber was either drawn to a smaller diameter or cut into 2- to 3-in. lengths with a knife having a serrated blade.

Herbicide release rates

Triplicate samples of each fluridone/PCL fiber were cut to the same length and weighed. The samples were then immersed in 25 or 50 mℓ of reconstituted hard water as the receiving fluid. The sealed containers with the fibers were agitated on an Eberbach shaker bath at approximately 22°C. We exchanged the receiving fluid periodically and assayed for fluridone content by measuring the ultraviolet (UV) absorbance on a Perkin-Elmer 575 spectrophotometer. The quantity of fluridone released was determined from Beer's Law plots of absorbance versus herbicide concentration.

RESULTS AND DISCUSSION

Selection of PCL for fiber trials

In earlier work with PCL, we had observed considerable differences in the melt-spinning characteristics and properties of fibers spun from different lots of Union Carbide's PCL-700 polymer. Therefore, a joint effort was made by the Institute and Union Carbide during the early part of this program to establish the optimum melt-viscosity range of the polymer to use for processing fluridone/PCL fibers. Union Carbide supplied us with three samples of PCL that differed significantly in viscosity. We then determined the melt index on a Tinius Olsen extrusion plastometer following the general procedures given in ASTM D-1238-79 and the melt-spinning characteristics using the Institute's ram extruder. The results of this study indicated that the PCL lot with a viscosity of 210,000 cps processed most easily and formed strong fibers that should be excellent carriers or binders for the fluridone. Therefore, we used PCL Lots 6322 and 6361, which had reported viscosities of about 210,000 and 225,000 cps, respectively, for the preparation of all fibers used in the field trials.

Blending of fluridone with PCL

Although the solvent-blending method gave the most homogeneous mixture of fluridone in PCL, it was determined quickly that the large quantities of solvent required would make this method impractical to use in production of large quantities of fibers. We next tried to blend PCL pellets as received with fluridone powder. The powder did coat the PCL pellets, but the blending was uneven, and fluridone tended to cake or ball into lumps. The feeding of this material through a screw extruder at temperatures above and below 150°C (the melting point of fluridone) gave fibers with poor uniformity and dispersion of fluridone. Thus, we decided to drop the pellet-powder method.

The most satisfactory technique was to mix finely ground PCL with the fluridone powder supplied by Elanco and feed this mixture directly to the extruder. Because of its low melting point (≃65°C) and low glass-transition temperature (-70°C), we had to grind the PCL on a Wiley mill with crushed dry ice. This procedure was laborious and time-consuming, but it gave a good blend. Later, we found a commercial supplier (Wedco, Inc.) who would cryogenically grind the PCL pellets for us at a reasonable cost. Their material was reduced to a particle size (<20 mesh) much smaller than that obtained on the Wiley mill, and gave the best blend with fluridone powder.

Selection of fluridone concentration and fiber diameters for test fibers

Because our goals in the field trials were to apply 2 lb of fluridone/acre and have the herbicide released over times of 20 and 40 days, we needed to establish preliminary fiber specifications that would give these values. We therefore spun fibers on the ram extruder containing 10, 20, and 40 percent by weight of fluridone and having diameters of 0.015 and 0.030 cm. When we conducted the in vitro release experiments, we found, as we had anticipated, that the fractional rate of release decreased and the duration of release increased as the initial loading of fluridone

was increased. We also found that the release rate decreased with increasing fiber diameter. Based upon these experiments, we decided that the goals for the field trials could be met using a 25:75 (w/w) fluridone/PCL blend and fiber diameters of 0.02 cm for 20 days of release and 0.04 cm for 40 days of release. With this information, we then proceeded to scale-up the production of the fibers.

Scale-up of fiber-processing procedures

Although we had experienced few difficulties in melt-spinning the fluridone/PCL blends on the ram extruder, we encountered a number of problems in spinning mixtures of these materials at feed rates considered feasible for producing fibers in quantities required for the field trials. Using the 0.75-in. extruder, we were successful in melt-spinning monofilaments at melt temperatures below the melting point of fluridone and air quenching them at low polymer feed rates (i.e., 0.2 lb/hr). Because these feed rates are not feasible for the large-scale production of fibers, we attempted to increase the number of filaments to achieve polymer feed rates of about 3 lb/hr. However, we were unable to melt-spin satisfactory fibers at these conditions below the melting point of fluridone. Apparently, at the higher feed rates we obtained less shear and mixing in the extruder. As a result, the blend was uneven and the fluridone particles caused numerous filament breaks.

To remove the fluridone particles and still maintain the higher throughputs, we attempted to spin yarn at temperatures and conditions which melted the fluridone. Fibers produced under these conditions were weak and tacky. They would tend to break or stick to the fiber guides or each other as they passed through air or a short water-quench bath.

Difficulties on the 0.75-in. extruder appeared to be due to inadequate mixing of PCL with fluridone and insufficient quenching in air and water. Therefore, we elected to make the fibers on the 1-in. extruder. The larger 1-in. extruder gives more mixing and is equipped with a long (10-ft), horizontal water-quench bath to provide quenching of fibers spun at temperatures above the melting point of fluridone. We found that we could melt-spin and water-quench 0.04-cm-diam or larger monofilaments at temperatures above the melting point of fluridone and at a polymer feed rate of about 3.5 lb/hr. However, the monofilaments were unusually difficult to quench, and it was necessary to keep the quench-bath temperature below 10°C to cool the 0.04-cm-diam fibers sufficiently for passing through the guides and over the take-up godets and collecting on the winder. We still had problems quenching and collecting 0.02-cm-diam fibers, but we found that we could produce these small-diameter fibers by simply drawing the 0.04-cm-diam fibers at a ratio of 4X through a 5.5-ft-long oven at 65°C.

Production of fibers for field trials

The first sets of fibers that we prepared were for field trials at Toledo Bend in Louisiana during June 1983. For this trial we attempted to produce 50 lb of 0.04-cm-diam fiber and 50 lb of 0.02-cm-diam fiber both from the 25:75 fluridone/PCL blend. We succeeded in preparing 80 lb of the 0.04-cm-diam fiber. Half of this material was cut into 2- to 3-in. lengths; the other half was drawn to 0.02 cm diameter and cut similarly. All material was shipped to Toledo Bend for placement in the field by the Corps of Engineers.

Because of time constraints, we were unable to measure the in vitro release rates of the fibers until after they had already been placed in the field. Surprisingly, we found that the 0.02-cm fiber gave complete release in 2 to 5 days, and the 0.04-cm fiber gave release in 15 to 20 days. We believe that these differences in actual versus predicted release rates are due to the process changes in spin temperature and quench conditions that we had to make in scaling-up from the ram extruder to the 1-in. screw extruder. Scanning electron microscopy of the surface of the fibers showed a porous structure with fluridone crystals present. This condition of the fibers would lead to a quick release of all fluridone and a shortened duration of action.

Before we prepared the next two lots of fibers for field trials in Florida and Washington State, we conducted a short trial to determine the effect of fiber diameter on fluridone release using the exact same procedure that was to be used in sample production. In this study, we used a new lot of PCL that was cryogenically ground by Wedco; we used a new lot of fluridone; and we used more optimum extrusion conditions (Table 1). Release studies on these fibers indicated that 0.08-cm-diam fibers would give 20 to 30 days of release, and 0.12-cm-diam fibers would release in 40 to 50 days. Thus, we prepared 50 lb of 0.08-cm-diam fiber and 50 lb of 0.12-cm-diam fiber for the trials in Florida.

Table 1

Conditions for Melt-Spinning Fibers Used in Field Trials*

	Temperature, °C									
Sample CO11-	*Feed Zone*	*Metering Zone*	*Melt Blender*	*Die*	*Feed Rate lb/hr (approx.)*	*Nominal Fiber Diameter, cm*	*Quantity, lb*	*Fluridone Lot No.*	*PCL-700 Lot No.*	*Field Trial*
29-1	76	217	162	140	3.5	0.04	40	827EG2	6322**	Toledo Bend
-2	62	186	158	120	3.5	0.02	40			
45-1	60	132	139	103	2.2	0.08	50	944EG2	6361†	Florida
-2	59	132	139	104	2.2	0.12	50			
45-3	60	130	138	106	2.2	0.08	50	944EG2	6361†	Washington
-4	57	125	132	100	2.2	0.04	46			

* All fibers contained 25 percent fluridone and 75 percent PCL-700 by weight and were in 2- to 3-in lengths.
** Ground at SRI on a Wiley mill with a 2-mm screen.
† Ground at Wedco, Inc., to <20 mesh.

Immediately after the production of fibers for Florida, 100 lb of fluridone-loaded fibers was produced for trials in Washington. Some preliminary release data from the fibers produced for the Florida trials indicated that the quantity of fluridone released per day from the long-term (≃40 days) fibers could be below the threshold level required to kill the weeds effectively. Therefore, for the Washington trial, we produced fibers of 0.08 cm for about 30 days of release and fibers of 0.04 cm for about 15 days of release.

The in vitro release rates of the fibers produced for the Florida and Washington field trials were much closer to those predicted than those prepared for the Toledo Bend trial (Table 2). In fact, for the Washington trials we were almost exactly on target. These data indicate that, once process conditions have been standardized and the same lots of PCL and fluridone are used, we can reliably predict the release rate and duration of action for the fluridone-loaded fibers.

Table 2

Summary of Fibers for Field Trials

Site	Fiber Size		Duration of Release, days	
	cm	*mil*	*Expected*	*In vitro*
Toledo Bend	0.02	8	15	2
	0.04	16	30	15
Florida	0.08	32	20	40
	0.12	48	40	80
Washington	0.04	16	20	20
	0.08	32	40	40

Effect of fluridone on fiber-processing conditions

Three samples of fluridone supplied by Elanco were used in this program. These samples were identified as Lots X36950 (97 percent active), 827EG2 (97.8 percent active), and 944EG2 (95 percent active). Considerable differences were observed in the processing characteristics of the lots as mixtures of each with PCL were melt-spun into fibers. Some differences were also observed in the appearance of pellets and fibers prepared from the mixtures.

Lot X36950, used in our melt-spinning trials on the ram extruder and in our initial studies on the 0.75-in. screw-type extruder, appeared to be very compatible with the PCL. We had no major problems in feeding mixtures of this sample and PCL to the extruders or in extruding fibers from the mixtures at temperatures below the melting point of fluridone. However, the second lot that we received (Lot 827EG2) and used in the preparation of the first lot of fibers for the Toledo Bend field trials did not appear to be as compatible with PCL as the first lot. This sample appeared to be more difficult to feed to the extruder when mixed with PCL powder or pellets, and we were unable to spin fibers at temperatures below the melting point of the fluridone from the mixtures. Also, pellets extruded from the powder/powder mixtures at temperatures below the melting point of the fluridone were rough along their surfaces. In addition to these differences, the fluridone did not appear to blend well with the PCL at temperatures above the melting point of the fluridone but migrated to the surface of the fibers.

The fluridone lot received last (Lot 944EG2, 95 percent active ingredients) and used in the preparation of fibers for the last two field trials appeared to have a greater plasticizing effect on the PCL than Lot 827EG2 (97.8 percent active ingredients), and this resulted in tacky fibers that were more difficult to quench. Therefore, it was necessary to melt-spin mixtures of this sample and PCL at lower temperatures than used in spinning mixtures of PCL and Lot 827EG2. In addition, this lot of fluridone did not tend to crystallize on the fiber surfaces as did Lot 827EG2.

To confirm these differences in spinning characteristics of the two fluridone samples, we prepared mixtures of each with portions of the same PCL powder sample (PCL Lot 6361) and spun fibers from each on the 1-in. Killion extruder. Temperatures ranging from 40° to 80°C lower were required for processing mixtures of fluridone Lot 944EG2 and PCL than were required for processing

Table 3

Effects of Fluridone Lot on Conditions for Spinning Fibers on the 1.0-in. Melt Extruder

Sample CO11-	Extrusion Temperature, °C: Feed Zone	Metering Zone	Melt Blender	Die	Fluridone Lot No
33-1	112	208	194	200	827EG2
2	112	208	194	175	(97.8% active
3	112	208	194	175	ingredients)
4	112	208	194	175	
39-1	81*	128*	137*	110*	944EG2
2	81	128	137	110	(95% active
3	81	128	137	110	ingredients)
4	81	128	137	110	

* Increasing spin temperature reduced melt viscosity rapidly, and fiber production was not possible.

mixtures of Lot 827EG2 as shown in Table 3. At temperatures used to process Lot 827EG2/PCL blends, the viscosity of Lot 944EG2/PCL blend was much too low to be fiber forming.

We also measured the melting point of each of the 25:75 fluridone/PCL samples on a Perkin-Elmer thermal analyzer. The respective melting points (at onset) of PCL Lot 6361 and 25:75 mixtures of fluridone Lots 827EG2 and 944EG2 with this PCL were 53.7, 48.9, and 46.2°C. This change in melt characteristics combined with the observed difference in melt-flow characteristics versus temperature suggests that the inactive material in the fluridone has a major effect on process conditions. However, if the variation in the lots of fluridone production can be minimized or eliminated, then standard conditions can be established to produce reliable fluridone-loaded fibers with predictable rates of release.

CONCLUSIONS AND RECOMMENDATIONS

From the results of the pilot-scale production trials with fluridone/PCL fibers, we conclude that:

a. Fibers with fluridone can be produced on a large scale.

b. Process conditions for producing the fibers are dependent on polymer viscosity, polymer particle size, and fluridone purity.

c. Fiber diameter and fluridone loading can be varied to achieve the desired release rates.

The recommendations suggested by this study include the following:

a. Quality control standards should be established for both fluridone and PCL.

b. Process conditions for producing the fibers should be optimized and then standardized.

c. Better methods for applying the fibers in the field should be evaluated.

d. The proper length of the fibers for best dispersion in the field and optimum release effects should be determined.

e. The modification of the fibrous system to produce pellets to fit existing herbicide application systems should be developed.

ACKNOWLEDGMENTS

The assistance of Ms. Gloria Y. Doby, Chemical Technician; Mr. George Ruff III, Senior Chemical Technician; Mr. Michael W. Price, Assistant Chemist; Ms. Brenda H. Perkins, Associate Biomathematician; and Dr. Janna D. S. Stevens, Research Biochemist, in preparing the fibers and conducting the in vitro experiments is most appreciated. We also wish to thank Dr. Howard E. Westerdahl and Dr. Thomas L. Hart of the Corps for their suggestions during the course of the program. Appreciation is also given to Dr. Danny H. Lewis, Vice-President of Research and Development for Stolle Research & Development Corporation, and to the U.S. Army Corps of Engineers Aquatic Plant Control Research Program for financial support of the project.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Preliminary Field Evaluation of Controlled-Release Fluridone Fibers

by

Howard E. Westerdahl,* Kurt Getsinger,* and Jerry Hall*

INTRODUCTION

The development of controlled-release (CR) herbicide formulations requires one to make major assumptions and decisions concerning the physical design of the CR carrier, rates of herbicide release from the CR carrier, herbicide concentrations and plant contact-time relationships to achieve control, and cost-effectiveness of the CR formulation or other benefits which make this formulation better than the conventional formulation. Often the result of these decisions terminates the further development of the CR carrier prior to even considering the formulation for field evaluation. The following is a summary of a preliminary small-scale field evaluation of CR fluridone fibers, which passed all previous decision points and preliminary laboratory testing concerning its feasibility as a new, competitive fluridone formulation. The evaluation of CR herbicide formulations in general requires cooperation and approval from the U.S. Environmental Protection Agency (USEPA) and responsible agencies prior to initiation of field tests. The States of Florida, Louisiana, and Washington approved of these tests and expressed interest in the CR technology under evaluation. These field tests were conducted in cooperation with Eli Lilly and Co., Southern Research Institute, and Stolle, Inc.

The objectives of the field evaluation were to: compare efficacy between CR fluridone fibers and the conventional SONAR 5P (Black Charm) pellet formulation; determine herbicide persistence in the treated water; and identify the extent of the control area. Four different size polycaprolactone (PCL) fibers, i.e. 8-, 16-, 30-, and 45-mil diameter, approximately 5 to 8 cm in length, were included in this field evaluation (Figure 1).

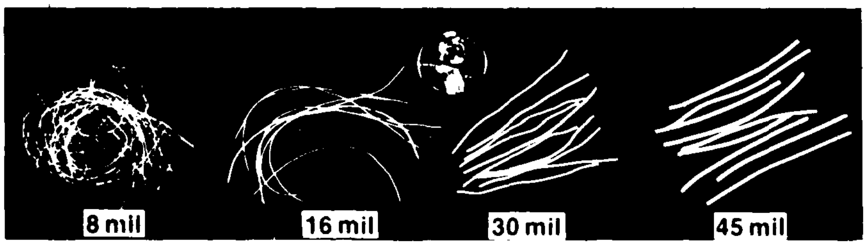


Figure 1. Controlled-release PCL fibers containing fluridone (26 percent a.i. by weight). NOTE: Smaller diameter fibers curl more than larger diameter fibers

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

CONTROLLED-RELEASE FLURIDONE FORMULATIONS

The fluridone release from these PCL fibers is controlled by diffusion, whereby the fractional rate of fluridone release is inversely proportional to the herbicide loading. During development it was observed that a small burst release of fluridone occurred within a few hours unless the fluridone-loaded fibers were coated with additional PCL. By increasing the loading of fluridone on the PCL fiber and then coating the fiber with PCL, the duration of fluridone release was extended. Likewise, by loading equally the PCL fiber of different diameters with a constant percent of fluridone (by weight) followed by coating the fiber with PCL, the rate of fluridone released was then regulated by the fiber's diameter. Figure 2 shows the fluridone release profiles of various diameter PCL fibers when loaded with a constant percent fluridone (26 percent by weight) and placed in jars of pond water and reconstituted hard water (USEPA 1975).

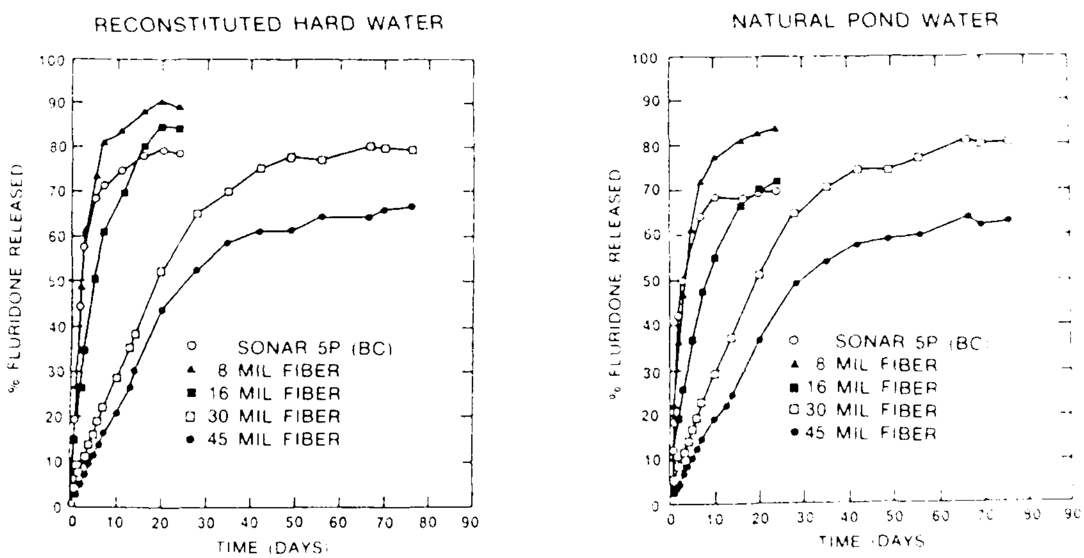


Figure 2. Release profiles of fluridone from controlled-release PCL fibers and SONAR 5P (after Van 1984)

The PCL fibers used in this field evaluation were approximately 5 to 7 cm in length with a fluridone loading of 26 percent a.i. and diameters of 8, 16, 30, and 45 mil. The smaller diameter fibers seemed to curl (Figure 1) and were more pliable than the larger diameter fibers. The higher fluridone loading (26 percent) compared to the conventional Black Charm pellets (5 percent) would allow the applicator to transport more herbicide and treat larger areas prior to reloading his boat. Other advantages including smaller storage areas and ease of handling the fibers make these formulations attractive.

Additional characteristics of these CR fibers and procedures involved in producing field-scale quantities have been described and summarized by Dunn (1983, 1984).

FIELD TEST SITES

Four test sites were selected in coordination with Eli Lilly personnel: Toledo Bend Reservoir, Louisiana; lateral 28 drainage canal in south Florida; Winchester wasteway, Washington; and, Pend Oreille River, Washington, near the City of Ione's river front park. Dominant submerged aquatic plants included watermilfoil, hydrilla, and pondweeds. Each of the sites were similar based on water depth (0.6 to 1.5 m) and plant biomass distribution. In Toledo Bend Reservoir and lateral 28 drainage canal, each treatment plot was 2.5 ha and the plots were separated from each other by approximately 600 m to minimize the chance of cross-contamination. The sites on the Pend Oreille River included two 1.8-ha plots and a 1.3-ha plot. Though the dominant plant was watermilfoil, pondweed (curly leaf) was intermixed with the watermilfoil. This test area had considerably higher water flow velocities (24 cms) than the reservoir sites (1 to 5 cms). The remaining site, Winchester wasteway, is located south of Ephrata, Wash. This particular site had an extensive population of pondweed (several species). Flow velocities exceeded 30 cms continuously throughout the study period. The treatment sites were approximately 600 m from each other and 800 m from the nearest irrigation intake. The treatment plots were each 1.8 ha with a channel width of approximately 27 m and a maximum water depth of 1.5 m or less.

HERBICIDE APPLICATION

Table 1 lists each CR formulation according to fiber diameter and estimated herbicide release period. The fluridone application of 2.2 kg a.i./ha was predetermined based on previous field data with the conventional SONAR 5P formulation. At Toledo Bend Reservoir on 15 June 83, the 8- and 15-mil fibers were distributed by hand from an airboat. The SONAR 5P was applied using a bow-mounted cyclone spreader. A small percentage of the fibers remained floating on the water surface and had to be wetted before they would sink. Likewise, during the week of 29 August 1983, the 30- and 40-mil fibers were distributed by hand from an airboat over each plot, respectively, in south Florida's lateral 28 drainage canal. Some of these larger fibers were observed floating on the water surface. The SONAR 5P pellets were distributed as previously described. The plots in the Pend Oreille River were treated on 9 September 1983; and Winchester wasteway was treated on 13 September 1983. The 15- and 30-mil fibers were applied to these plots in Washington as previously described, except the fibers were prewetted prior to

Table 1
Fluridone Formulations and Projected Herbicide Release Period

Formulation	*Percent Fluridone (by weight)*	*Release Period*
SONAR 5P (BC)	5	Variable
CR fluridone fiber, 8 mil	26	2 days
CR fluridone fiber, 16 mil	26	10 - 15 days
CR fluridone fiber, 30 mil	26	20 - 30 days
CR fluridone fiber, 45 mil	26	40 - 50 days

distributing over the plot. No fibers were observed to be floating immediately following hand dispersal. The SONAR 5P formulation was applied with a calibrated hand-held cyclone spreader.

TEST SITE MONITORING

Fluridone efficacy

Estimates of efficacy were based on response categories (Table 2). All plots were evaluated at approximately monthly intervals. Longer periods between observations were dependent on plant response and time of year considerations.

Table 2
Categories of Treatment Efficacy and Control Duration

Category	*Plant Response*
1	No visible effects
2	Herbicide damage evident on meristems; less than 50 percent biomass reduction
3	Meristems, stems, and foliage are significantly damaged; more than 50 percent biomass reduction
4	No evidence of target plants remaining
5	Regrowth evident in less than 50 percent of the plot area
6	Regrowth evident in more than 50 percent of the plot area
7	Vegetation reestablished, as prior to treatment

Distribution of fluridone in water

The fluridone distribution was determined prior to treatment and on posttreatment days 1, 7, 14, 21, 35, 42, and 49. Analysis of samples after posttreatment day 21 depended upon whether fluridone residues were present. Water samples were collected within and outside the treatment plots to assess vertical and horizontal fluridone distribution.

Within-plot distribution. Five sampling stations were established: one in the center of each quadrant and one in the center of the plot. At each station, 1-ℓ water samples were taken from mid-depth in the water column. All samples were refrigerated prior to shipment to Eli Lilly, Inc., in Greenfield, Ohio, for analysis. Only the center samples were analyzed initially to determine if residues were present. Additional analyses were terminated if residues were not detected.

Outside plot distribution. A 1-ℓ water sample was collected at mid-depth on each aforementioned sampling date approximately 50 m outside the perimeter of each plot. However, in the flowing water sites, composite mid-depth water samples were taken from three locations 50 m upstream, mid-plot, and 50 m downstream on a transect across the channel. All samples were refrigerated prior to shipment to Eli Lilly, Inc., in Greenfield, Ohio, for analysis.

FLURIDONE RESIDUE

Fluridone concentrations ranged from 1 to 18 $\mu g/\ell$ through posttreatment day 7 in the mid-plot location of all CR treatment plots at Toledo Bend Reservoir, and

through posttreatment day 21 in the lateral 28 drainage canal (Table 3). Hence, additional fluridone analyses of remaining samples obtained at different locations within each plot on each sampling date were terminated. Only on posttreatment day 1 in lateral 28 drainage canal was an unusually high fluridone concentration measured, i.e. 39 $\mu g/l$. This value would suggest either a spike fluridone loading from SONAR 5P or contaminatin of the water sample during handling.

Table 3
Fluridone Concentrations in Water from Test Sites

Test Site	*Posttreatment Days*	*Fluridone Concentration, μg/l*				
		8 mil	*16 mil*	*30 mil*	*45 mil*	*SONAR 5P*
Toledo Bend Reservoir	Pre-	1	ND	*	*	ND
	1	2	8	*	*	8
	7	2	4	*	*	4
	14	ND	3	*	*	2
	21	ND	ND	*	*	ND
Lateral 28 drainage canal	Pre-	*	*	ND	ND	2
	1	*	*	18	9	39
	3	*	*	17	6	6
	7	*	*	10	7	5
	14	*	*	7	3	7
	21	*	*	2	3	1
Pend Oreille River	Pre-	*	ND	ND	*	ND
	1	*	0.7	0.2	*	2.2
	3	*	ND	0.2	*	1.2
	7	*	ND	ND	*	ND
	14	*	ND	ND	*	ND
Winchester wasteway	Pre-	*	ND	ND	*	ND
	1	*	ND	ND	*	ND
	3	*	ND	ND	*	ND
	7	*	ND	ND	*	ND

Note: ND = not detected.
* These fibers were not evaluated at this site.

HERBICIDE EFFICACY

Toledo Bend Reservoir

The 8-mil PCL fiber provided less than 50 percent control of watermilfoil at 12 weeks posttreatment. Hydrilla exhibited 70 percent control within the same time period; however, the pondweeds were 100 percent controlled within 18 weeks posttreatment. No plant injury was observed outside the treated areas of those plots treated with the PCL fibers. Rapid regrowth of hydrilla and watermilfoil was noticed from posttreatment weeks 12 to 18. The 16-mil fluridone PCL fibers and the SONAR 5P provided comparable control within 8 weeks posttreatment. After 12 to 18 weeks posttreatment, nearly 100 percent control of watermilfoil and hydrilla was observed in the 16-mil plot versus the plot treated with conventional SONAR 5P pellets, which exhibited a 100 percent control of hydrilla during this same period. After 18 weeks posttreatment, regrowth of watermilfoil and hydrilla was appar nt near the sediment in the 16-mil PCL plots. The macrophytes within the plot treated with SONAR 5P remained nearly 95 to 100 percent controlled, i.e. very little evidence of regrowth. However, plant injury was observed outside of the treated area.

Lateral 28 drainage canal

At approximately 7 weeks posttreatment, all three treatment plots were approximately 50 percent controlled. Slightly more hydrilla injury was observed in the 30- and 40-mil PCL plots more than in the SONAR 5P plots. By December (16 weeks posttreatment), the hydrilla treated with the CR fibers were approximately 95 percent controlled. Only the upstream quarter of each plot was unaffected by the CR fibers. The hydrilla within the buffer zones between the treatment plots remained unaffected. Apparently the majority of fibers applied on the upstream quarter of these plots either travelled downstream prior to sinking or herbicide dilution caused by the moving water did not permit a contact time of sufficient duration to control the hydrilla. The plot treated with SONAR 5P exhibited virtually 100 percent control of hydrilla after 16 weeks posttreatment. Additional inspections will be made to observe the rate of hydrilia regrowth in the treated areas.

Pend Oreille River

Prior to ice cover, i.e. 8 weeks posttreatment, no efficacy was observed in any of the treated plots. However, at 12 weeks posttreatment, the plot treated with the 16-mil fluridone fiber appeared to show herbicide damage, i.e. meristem transparency, compared to the nearby SONAR 5P plot near the Ione city park. Limited observations were made because of ice cover on the river. These plots will be evaluated during the spring and summer of 1984.

Winchester wasteway

None of the formulations were effective in controlling the submerged plants. Symptoms of plant injury were not found at any time through 12 weeks posttreatment. During the spring and summer of 1984, these sites will also be evaluated.

CONCLUSIONS AND RECOMMENDATIONS

From the preliminary field evaluation of PCL fluridone fibers, it was concluded that the CR fibers were effective. Moreover, the herbicide's control area was better defined in Toledo Bend Reservoir with the CR fibers than with the SONAR 5P. The other treatment areas in south Florida demonstrated that SONAR 5P and the CR fibers performed equally well in controlling hydrilla within the treated areas only. Based on these results, it would appear that at 2.2 kg a.i./ha fluridone released over a 15- to 30-day period should provide excellent control of hydrilla, watermilfoil, and pondweeds in lakes and in bodies of slow-moving water.

Based on the results to date, it is recommended that additional research and testing be performed on the PCL controlled-release system. First, pelletized versions of the fibers should be developed to take advantage of using conventional application techniques for broadcasting and to permit rapid sinking of the formulation in flowing water. Second, laboratory and field comparisons of CR fluridone pellets, fibers, and SONAR 5P should be conducted during FY 1984. If the fibers are to be successful commercially, additional research is needed to develop

equipment that would permit rapid dispersal of these fibers and at the same time permit prewetting. Finally, since efficacy of all formulations was not clearly demonstrated in the flowing water sites of Washington, it is recommended that higher treatment rates with fluridone delivery over a 15- to 30-day period be evaluated in the flowing water test facility at the Waterways Experiment Station prior to additional field testing.

REFERENCES

Dunn, R. L., et al. 1983. "Fiber Formulations for the Controlled Release of Aquatic Herbicides," *Proceedings, 17th Annual Meeting, Aquatic Plant Control Research Program, 16-18 November 1982, Sacramento, California*, Miscellaneous Paper A-83-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Dunn, R. L., Dappert, T. O., and Stoner, W. C., Jr. 1984. See pp 125-132 of this proceedings.

U. S. Environmental Protection Agency. 1975. "Methods for Acute Toxicity Tests with Fish, Macroinvertebrates, and Amphibians," EPA-660/3-75-009, Corvallis Environmental Research Laboratory, Corvallis, Oreg.

Van, T. 1984. See pp 104-111 of this proceedings.

AD-P003 611

ECOLOGY OF AQUATIC PLANT SPECIES

Effects of Sediment Composition

by
John W. Barko* and R. Michael Smart*

BACKGROUND

Since nearly the turn of this century it has been recognized that the nature of bottom sediments affects the growth of rooted submersed aquatic vegetation (Pearsall 1920; Misra 1938; Walker 1972; Segal 1982). Associated mechanisms, however, have not been clearly established, and it remains difficult to predict or manage the growth of these plants without a better understanding of the involvement of specific sediment factors.

Different aquatic plant species appear to vary in the magnitude of their response to sediment conditions. For example, in an earlier investigation of sediment-phosphorus mobilization by submersed aquatic plants (Barko and Smart 1980), the growth of *Myriophyllum spicatum* varied over a broad range, whereas the growth of *Egeria densa* did not vary on the same array of sediments (Figure 1). In nature, such differences in responsiveness to sediment conditions may influence the species composition of submersed aquatic plant communities.

There is an apparent association during lake aging between increasing sediment organic matter and decline of submersed aquatic vegetation (Walker 1972; Wetzel 1979; Carpenter 1981). Moreover, the spatial distribution of individual plant species seems to vary with sediment organic content (Macan 1977). These observations, considered collectively, suggest that the effect of sediments on submersed aquatic plants may in some way be related to sediment organic matter content.

Additions of vegetative organic matter to sediment can substantially reduce the growth of submersed aquatic plants. For example, in the investigation of Barko and Smart (1983), the addition of small amounts of dried cattail litter to an inorganic control sediment resulted in a 90 percent reduction in the growth of *Hydrilla verticillata* (Figure 2). Since little is known, however, about organic loading processes in natural aquatic systems, the applicability to nature of these results obtained on artificially loaded sediments has been open to question. For this reason, the growth of two invasive aquatic plant species, *H. verticillata* and *M. spicatum*, is critically examined here in relation to the physical and chemical composition of 40 natural sediments from 17 geographically widespread North American lakes (Table 1).

---

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

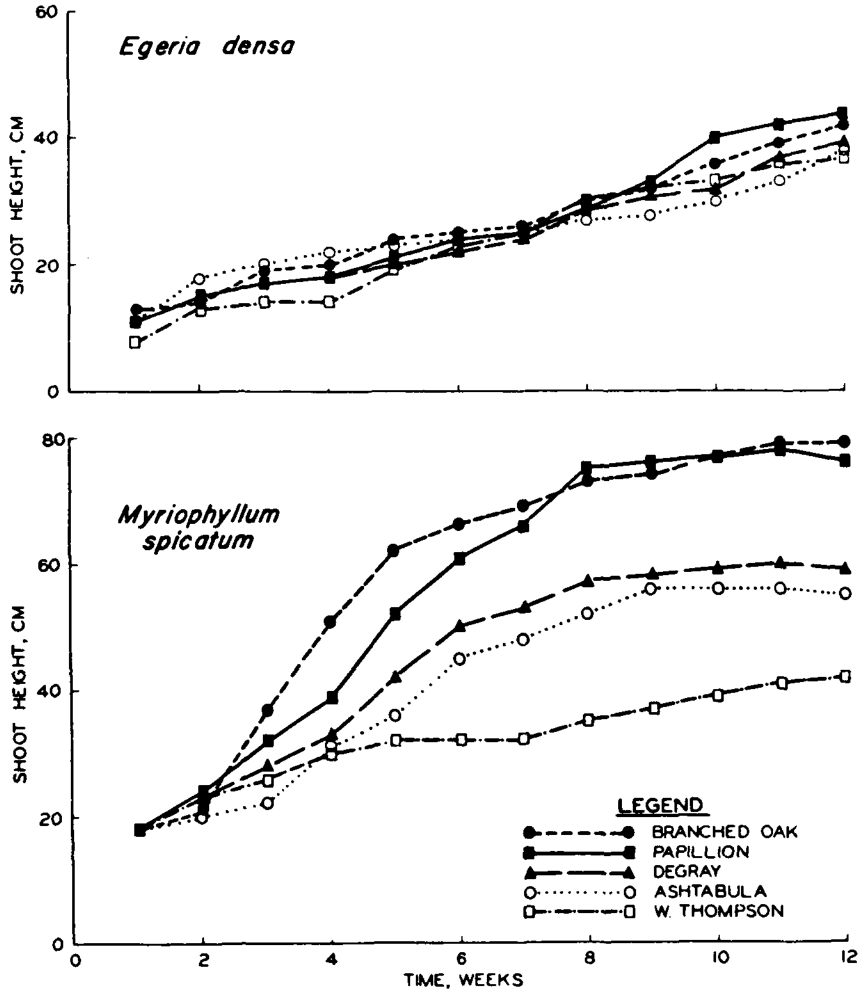


Figure 1. Growth, as shoot height, of *Egeria densa* and *Myriophyllum spicatum* on five different reservoir sediments. Values of shoot height are means of four replicates. Data derive from the study of Barko and Smart (1980)

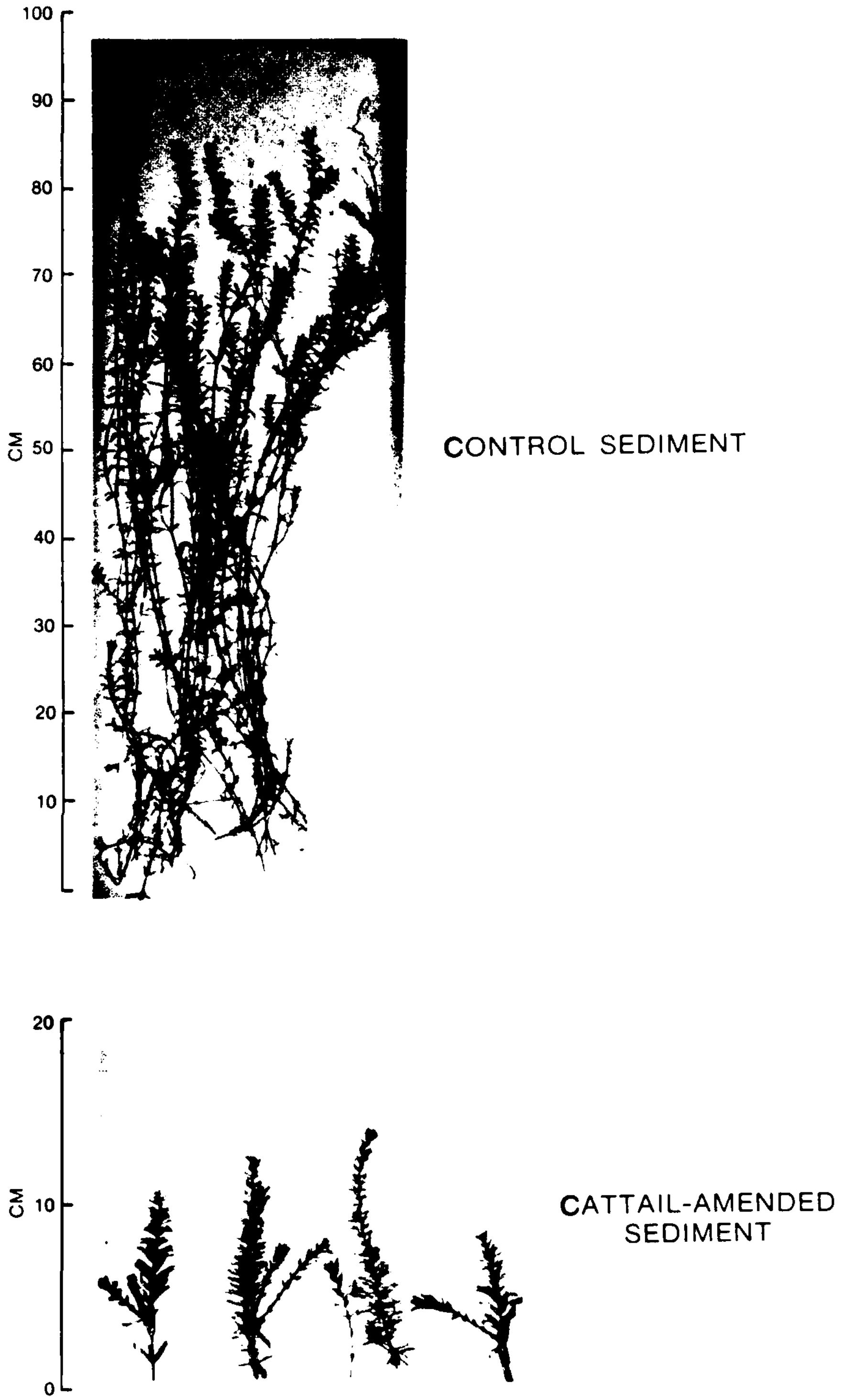


Figure 2. ***Hydrilla verticillata*** **after 6 weeks growth on an inorganic control sediment and on the same sediment amended by addition of dried cattail litter, representing a 5 percent increase in total sediment organic content. Photographs derive from the study of Barko and Smart (1983)**

Table 1

Identification and Location of Lakes from Which Bottom Sediments Were Obtained*

Lake	*Location*	*Site Number*
Deer Point	Florida, U.S.A.	1
Kerr	Florida, U.S.A.	2
Rodman	Florida, U.S.A.	2
Okeechobee	Florida, U.S.A.	2
Seminole	Georgia, U.S.A.	3
Parr Pond	South Carolina, U.S.A.	2
Brown's	Mississippi, U.S.A.	2
Openwood	Mississippi, U.S.A.	1
Farm Pond	Mississippi, U.S.A.	1
Chenango	New York, U.S.A.	2
Duck	Michigan, U.S.A.	2
Wintergreen	Michigan, U.S.A.	2
Chemung	Ontario, Canada	2
Buckhorn	Ontario, Canada	2
Mendota	Wisconsin, U.S.A.	1
Wingra	Wisconsin, U.S.A.	4
Washington	Washington, U.S.A.	4

* Lakes include natural water bodies and reservoirs. Site number designates the number of sites independently sampled within each lake. Lakes and sites were selected to provide a broad variety of sediments.

MATERIALS AND METHODS

Surficial sediments were collected with small hand-held dredges. Sediment samples (about 24 ℓ) from each site were sieved (2 mm plastic mesh), thoroughly mixed, then allowed to equilibrate for several weeks prior to the initiation of study. A variety of sediment characteristics, potentially affecting plant growth, were determined (Table 2). This characterization indicated broad ranges in physical and chemical composition.

The investigation was conducted in large, white, fiberglass tanks, housed in the Environmental Laboratory greenhouse facility (Barko and Smart 1981). Irradiance was reduced to 50 percent full sunlight beneath neutral density shade fabric. Water temperature was maintained at 25° ± 1°C. The solution used in the tanks was identical to that described in Barko, Hardin, and Matthews (1982) except for the addition of $Ca(NO_3)_2 \cdot H_2O$ providing 5.0 mg N/ℓ.

After 5 weeks of growth, plant roots and shoots were harvested, measured, oven dried (80°C), and weighed. Growth was determined as total dry weight biomass on the various sediments.

RESULTS AND DISCUSSION

From computer-assisted linear and nonlinear analyses of data, growth of both species was best related in a negative exponential manner to total sediment organic matter content (Figure 3), or to sediment variables intrinsically correlated with organic matter (Table 3). Shoot length and the ratio of root-to-shoot biomass were positively and negatively correlated, respectively, with total biomass (Table 4). Thus, plant stature and biomass allocation, in addition to total biomass, were affected by sediment composition.

Table 2

Physical and Chemical Characteristics of Selected Lake Sediments*

Characteristic	*Min*	*Max*	*Mean*
Texture, %			
Sand	2	95	40
Silt	1	77	44
Clay	3	65	17
Density, g/cc	1.01	1.75	1.24
Moisture, %	27	93	67
Organic matter, %			
Total	2	63	24
Humics	0.1	21.4	5.9
Nonhumics	1.2	49.2	18.4
Total Kjeldahl N, mg/g	0.3	23.8	7.8
I.W. conductivity, µS/cm	171	1618	679
I.W. pH, std. units	5.8	7.1	6.7
I.W. soluble elements, mg/ℓ			
Organic carbon	14	133	41
Inorganic carbon	3	205	85
Ammonium - N	1.6	45.6	16.8
Orthophosphate - P	0.04	9.36	1.15
Sodium	1.7	89.0	16.7
Potassium	0.7	22.0	6.0
Calcium	12	133	77
Magnesium	1.2	82.5	19.6
Iron	0.0	71.0	11.1
Manganese	0.0	22.5	2.9

*All units of mass are based on sediment dry weight except density and moisture, which are based on wet weight. The abbreviation (I.W.) indicates sediment interstitial water. Descriptive statistics were calculated from mean values (n=2) for 40 sediments. Min = minimum value. Max = maximum value. Mean = average (n=40).

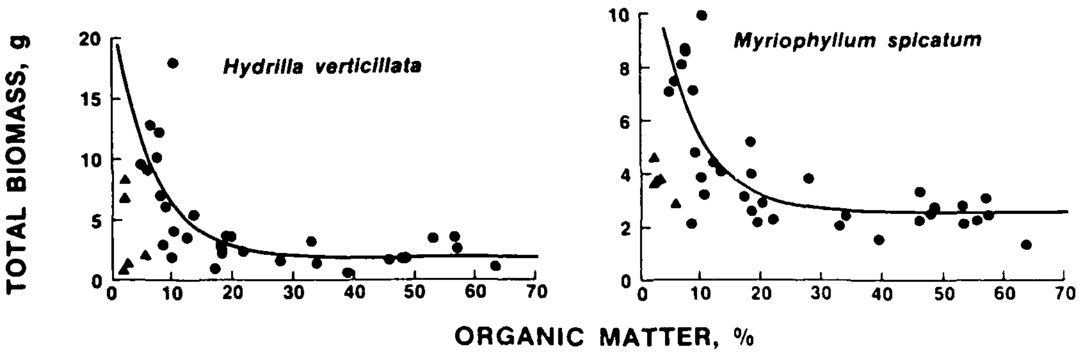


Figure 3. Relationship between the growth (as total dry weight biomass, roots plus shoots) of *H. verticillata* and *M. spicatum* and sediment organic matter. Values of dry weight biomass are means of four replicates. Sediment organic matter was determined from weight loss on ignition (550°C) and separately also by measurement of CO_2 evolution (infrared detection) on ignition. Sediment organic carbon = 0.53 × sediment organic matter ($r^2 = 0.98$ at $p < 0.001$). Values designated as Δ identify sediments containing > 75 percent sand (see text); these were excluded from curve fitting

Table 3
Sediment Factors Intrinsically Correlated with Sediment Organic Content*

Sediment Factor	Correlation Coefficient
Nonhumics	0.97
Total Kjeldahl N	0.94
Sediment moisture	0.85
Total humics	0.79
Sediment density	-0.76

* All correlations are significant at $p < 0.001$.

Table 4
Growth Variables, Shoot Length, and Root:Shoot Biomass in Relation to Total Biomass of *Hydrilla* and *Myriophyllum**

Species	Growth Variable	Relationship**	Correlation Coefficient
Hydrilla	Shoot length, cm	6.3 × TB + 33	0.88
	Root:shoot biomass	-0.01 × TB + 0.14	-0.76
Myriophyllum	Shoot length, cm	9.0 × TB + 39	0.84
	Root:shoot biomass	-0.03 × TB + 0.34	-0.79

* All correlation coefficients are significant at $p < 0.001$.

** Relationships are linear expressions in which TB = total biomass.

Plant growth varied over approximate tenfold and twentyfold ranges in *M. spicatum* and *H. verticillata*, respectively (Figure 3). Most of this variability occurred on sediments with an organic content of <15 percent. On sediments with >15 percent organic matter, biomass was rather uniformly reduced to the lower end of the growth range. Despite their low organic content, sediments with >75 percent sand (specifically identified in Figure 3) supported relatively poor plant growth.

It is difficult to explain the diminished growth of submersed aquatic plants on organic sediments because of the complexity of potentially interacting mechanisms. Nutrient limitation due to complexation with organic matter represents one possible mechanism (Sikora and Keeney 1983). Another is growth inhibition by anaerobically produced phytotoxins (Armstrong 1975). Root metabolism may be upset by inadequate oxygen supply (Armstrong 1978; Drew and Lynch 1980). Growth may also be reduced simply by physical constraints on plant rooting due to low sediment density (note the negative relationship between organic matter and density in Table 3). Diminished growth on very sandy sediments, because of their inherently infertile nature, probably reflects a general nutrient inadequacy. On these sediments small accumulations of organic matter may stimulate growth by increasing nutrient supply and enhancing sediment ion exchange properties (Sand-Jensen and Søndergaard 1979; Kiørboe 1980).

CONCLUSIONS

From these results, it is concluded that, under otherwise uniform environmental conditions, the growth of submersed aquatic vegetation can be expected to be

relatively poor, both on highly organic sediments and on sediments with a high (>75 percent) sand fraction. While numerous other environmental factors have been demonstrated also to affect plant growth (Davis and Brinson 1980; Barko 1981; Spence 1982), sediment organic content and texture, determined by rather simple analytical procedures (Allen et al. 1974; Patrick 1958), should be useful in assessing the site-specific relative growth potential of submersed aquatic vegetation.

ACKNOWLEDGMENTS

Co-workers D. G. McFarland, M. S. Hennington, and R. H. Warren provided technical assistance. Support for this research effort was provided by the U.S. Army Corps of Engineers Aquatic Plant Control Research Program (APCRP). This article was written using some of the data from a more comprehensive study scheduled to be published as an APCRP technical report in 1985.

REFERENCES

Allen, S. E., et al. 1974. *Chemical Analysis of Ecological Materials*, Wiley, New York.

Armstrong, W. 1975. "Waterlogged Soils," *Environment and Plant Ecology*, J. R. Etherington, ed., Wiley, New York, pp 181-218.

Armstrong, W. 1978. "Root Aeration in the Wetland Conditions," *Plant Life in Anaerobic Environments*, D. D. Hook and R. M. M. Crawford, eds., Ann Arbor Science Publishers, Ann Arbor, Mich., pp 269-297.

Barko, J. W. 1981. "The Influence of Selected Environmental Factors on Submersed Macrophytes - A Summary," *Proceedings of the Symposium on Surface Water Impoundments ASCE, June 2-5, 1980, Minneapolis, Minnesota*, H. G. Stephen, ed., American Society of Civil Engineers, New York, pp 1378-1382.

Barko, J. W., and Smart, R. M. 1980. "Mobilization of Sediment Phosphorus by Submersed Freshwater Macrophytes," *Freshwater Biology*, Vol 10, pp 229-238.

Barko, J. W., and Smart, R. M. 1981. "Comparative Influence of Light and Temperature on the Growth and Metabolism of Selected Submersed Freshwater Macrophytes," *Ecological Monographs*, Vol 51, pp 219-235.

Barko, J. W., and Smart, R. M. 1983. "Effects of Organic Matter Additions to Sediment on the Growth of Aquatic Plants," *Journal of Ecology*, Vol 71, pp 161-175.

Barko, J. W., Hardin, D. G., and Matthews, M. S. 1982. "Growth and Morphology of Submersed Freshwater Macrophytes in Relation to Light and Temperature," *Canadian Journal of Botany*, Vol 60, pp 877-887.

Carpenter, S. R. 1981. "Submersed Vegetation: An Internal Factor in Lake Ecosystems Succession," *American Naturalist*, Vol 118, pp 372-383.

David, G. J., and Brinson, M. M. 1980. "Responses of Submersed Vascular Plant Communities to Environmental Change," Fish and Wildlife Service Technical Report FWS/OBS-79/33, U.S. Department of Interior, Kearneysville, W. Va.

Drew, M. C., and Lynch, J. M. 1980. "Soil Anaerobiosis, Microorganisms, and Root Function," *Annual Review of Phytopathology*, Vol 18, pp 37-66.

Kiørboe, T. 1980. "Distribution and Production of Submerged Macrophytes in Tipper Grund (Ringkøbing Fjord, Denmark), and the Impact of Waterfowl Grazing," *Journal of Applied Ecology*, Vol 17, pp 675-687.

Macan, T. T. 1977. "Changes in the Vegetation of a Moorland Fishpond in Twenty-one Years," *Journal of Ecology*, Vol 65, pp 95-106.

Misra, R. D. 1938. "Edaphic Factors in the Distribution of Aquatic Plants in the English Lakes," *Journal of Ecology*, Vol 26, pp 411-451.

Patrick, W. H. 1958. "Modification of Method of Particle Size Analysis," *Soil Science Society of America Proceedings*," Vol 22, pp 366-367.

Pearsall, W. H. 1920. "The Aquatic Vegetation of the English Lakes," *Journal of Ecology*, Vol 8, pp 163-199.

Sand-Jensen, K., and Søndergaard, M. 1979. "Distribution and Quantitative Development of Aquatic Macrophytes in Relation to Sediment Characteristics in Oligotrophic Lake Kalgaard, Denmark," *Freshwater Biology*, Vol 9, pp 1-11.

Segal, S. 1982. "General Trends in Structure Development during Succession of Aquatic Macrophyte Vegetation," *Studies on Aquatic Vascular Plants, Proceedings of the International Colloquium on Aquatic Vascular Plants, Brussels, 23-25 January 1981*, J. J. Symoens, S. S. Hooper, and P. Compere, eds., Royal Botanical Society of Belgium, Brussels, pp 249-256.

Sikora, L. J., and Keeney, D. R. 1983. "Further Aspects of Soil Chemistry Under Anaerobic Cenditions," *Mires: Swamp, Bog, Fen, and Moor, A. General Studies*, A. J. P. Gore, ed., Elsevier Scientific Publishing Company, Amsterdam, pp 247-256.

Spence, D. H. N. 1982. "The Zonation of Plants in Freshwater Lakes," *Advances in Ecological Research*, Vol 12, pp 37-125.

Walker, D. 1972. "Direction and Rate in Some British Post-Glacial Hydroseres," *Studies in the Vegetational History of the British Isles*, D. Walker and R. G. West, eds., Cambridge University Press, Cambridge, pp 117-139.

Wetzel, R. G. 1979. "The Role of the Littoral Zone and Detritus in Lake Metabolism," *Archiv für Hydrobiologie*, Vol 13, pp 145-161.

ECOLOGY OF AQUATIC PLANT SPECIES

Effects of Water Chemistry on Aquatic Plant Species: Preliminary Studies on *Myriophyllum spicatum*

by
R. Michael Smart* and John W. Barko*

There have been many studies attempting to relate the growth and distribution of subn rsed aquatic plants to environmental parameters. Parameters most frequently considered are temperature, light, water depth, hydraulic conditions, sediment composition, and water chemistry. As part of a continuing effort aimed at understanding the ecological relationships among introduced and native submersed aquatic plant species, we have previously considered the effects of light and temperature (Barko and Smart 1981; Barko, Hardin, and Matthews 1982; Barko and Filbin 1983) and are currently examining the effects of sediment composition (Barko and Smart 1983, Barko and Smart 1984). Information obtained to date indicates that submersed aquatic plants are tolerant of fairly broad ranges in light intensity and temperature. Sediment composition appears to be of primary importance in affecting the growth and distribution of submersed aquatic plants; however, differences in solution composition appear to moderate species responses to sediment composition (Barko 1982, 1983), suggesting that the sedimentary environment alone may not exert a controlling influence on the distribution of individual species.

Water chemistry has long been considered a primary factor affecting the distribution of submersed aquatic plant species, and there have been many field studies relating distribution to water chemistry (Moyle 1945; Spence 1967; Hutchinson 1970; Seddon 1972; Hellquist 1980; Kadono 1982). One of the problems with the above studies is that sites differing in water chemistry are likely to differ in other environmental parameters as well. Therefore, it is difficult to attribute observed species distributions solely to water chemistry. Another problem with this type of study is the high degree of intercorrelation among water chemistry parameters. For example, increases in dissolved inorganic carbon (DIC) or alkalinity are generally accompanied by increases in Ca, pH, and electrical conductivity. For both of the above reasons, care must be exercised in interpreting distributional patterns, and establishment of causal relationships between species distribution and specific water chemistry parameters is difficult. To avoid these difficulties, we elected to study the effects of specific water chemistry parameters on growth and photosynthesis of submersed aquatic plants under otherwise uniform environmental conditions.

The preliminary results reported here derive from a larger investigation, results of which will be reported in an Aquatic Plant Control Research Program (APCRP) technical report. The objective of this first year of effort was to determine the individual and combined effects of specific water chemistry parameters on the

* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

growth of *Myriophyllum spicatum*. Subsequent studies will be expanded to include the effects of water chemistry parameters on photosynthesis and growth of a variety of introduced and native aquatic plant species.

METHODS AND MATERIALS

The experiments were conducted in lucite columns in a growth chamber at the Waterways Experiment Station (WES). The experimental columns contained 15 ℓ of solution and 3.5 ℓ of Browns Lake (at WES) sediment as a rooting substrate. Half of the solution volume was replaced each week to minimize changes in solution composition. Individual treatments were replicated four times and each column was planted with four apical tips. Plants were grown for 6 weeks under photosynthetically active radiation (PAR) levels of approximately 350 $\mu E/m^2/sec$ during a photoperiod of 14 hr. Temperature was maintained at 25°C. Aeration and mixing were provided by administering humidified air at a rate of 17 ℓ/hr.

Experiment 1

The objective of the first experiment was to determine the effects of cation and inorganic carbon concentrations on growth of *M. spicatum*. The experimental design was a 3 × 3 factorial with three levels of major cations (Ca, Mg, Na, K) and three levels of dissolved inorganic carbon. Experimental solutions, described in Table 1, were based on data provided for bicarbonate lakes by Hutchinson (1957).

Table 1
Composition and Characterization of Experimental Solutions

Treatment Levels		*Solution Characteristics*										
Carbon	*Cation*	*Ca mg/ℓ*	*Mg mg/ℓ*	*Na mg/ℓ*	*K mg/ℓ*	*DIC mg/ℓ*	*Cl mg/ℓ*	*SO_4 mg/ℓ*	*Cond. µS/cm(25°C)*	*pH (eq.)*	*I.S.* mM*	*ALK.* meq/ℓ*
Low	Low	10	1.7	2.8	1.0	3.5	7	14	100	7.5	1.3	0.27
Low	Mid	30	5.0	8.4	3.1	3.5	32	57	275	7.5	3.9	0.27
Low	High	60	10.1	16.9	6.1	3.5	69	120	505	7.5	7.9	0.27
Mid	Low	10	1.7	8.0	1.0	10.5	2	4	110	8.0	1.4	0.86
Mid	Mid	30	5.0	8.4	3.1	10.5	22	41	260	8.0	3.7	0.86
Mid	High	60	10.1	16.9	6.1	10.5	58	107	490	8.0	7.7	0.86
High	Low	10	1.7	28.1	1.0	21.0	2	42	175	8.3	2.2	1.73
High	Mid	30	5.0	8.4	3.1	21.0	9	17	230	8.3	3.5	1.73
High	High	60	10.1	16.9	6.1	21.0	44	83	490	8.3	7.5	1.73

* I. S. = Ionic Strength, ALK. = Alkalinity.

Experiment 2

The objective of the second experiment was to study the effects of individual cations on growth of *M. spicatum* under low carbon conditions. This experiment consisted of two major parts: (1) individual cation additions to low cation, low carbon solution; and (2) individual cation deletions from high cation, low carbon solution. Cation additions involved increases in specific cation concentration from the low level to the high level (Table 1), while deletions consisted of decreases in specific cation concentrations from the high level to the low level (Table 1).

RESULTS AND DISCUSSION

Experiment 1

Increases in either cations or carbon over levels of these in low cation, low carbon solution resulted in increased growth of *M. spicatum* (Figure 1). Increases in carbon resulted in greater growth than did increases in cation concentration. Although increases in both cation and carbon concentrations resulted in the greatest total biomass accrual, much of this apparent biomass consisted of ash (principally $CaCO_3$) and comparisons should be based on ash-free biomass accrual. In terms of ash-free biomass, there were no significant differences in growth at the higher carbon levels due to cation concentration, and there were also no significant differences in growth between the two higher levels of carbon. Cation effects on growth of *M. spicatum* reported earlier (Barko 1983) therefore appear to occur only under low carbon conditions. Likewise, increased growth due to addition of dissolved inorganic carbon also occurred only under low carbon conditions.

Experiment 2

The effects of specific cations on growth and senescence of *M. spicatum* under conditions of low carbon are shown in Figure 2. Individual addition of K, Mg, or Ca to the low cation, low carbon solution resulted in increased growth of *M. spicatum* (Figure 2a). The combined addition of all four major cations did not result in a further increase in growth over that obtained by individual addition of K, Mg, or Ca. Increases in Na had no effect on growth. Increased C, shown for comparison, resulted in greatly increased growth even at the low level of cations.

Plants grown in low cation, low carbon solution exhibited a high degree of premature tissue senescence in addition to relatively depressed growth. While addition of K lessened senescence, adding Ca either alone or in combination with other cations virtually prevented the onset of premature senescence (Figure 2b). Increased C, again shown for comparison, similarly prevented senescence under low cation conditions.

Decreasing the concentration of K, Ca, or all major cations from the high level to the low level resulted in decreased growth (Figure 2c) and increased senescence (Figure 2d) under low carbon conditions. The effect on senescence of decreasing the Ca concentration was essentially equivalent to that of decreasing all major cations.

CONCLUSIONS

The effect of water chemistry on the growth of *M. spicatum* appears to involve primarily the availability of dissolved inorganic carbon. Under low carbon conditions, specific cations (Ca and to a lesser extent K) may be involved in carbon acquisition (Lowenhaupt 1956; Lucas and Dainty 1977). The combined effects of low levels of Ca and low C availability can result in decreased growth and the development of premature senescence in *M. spicatum*.

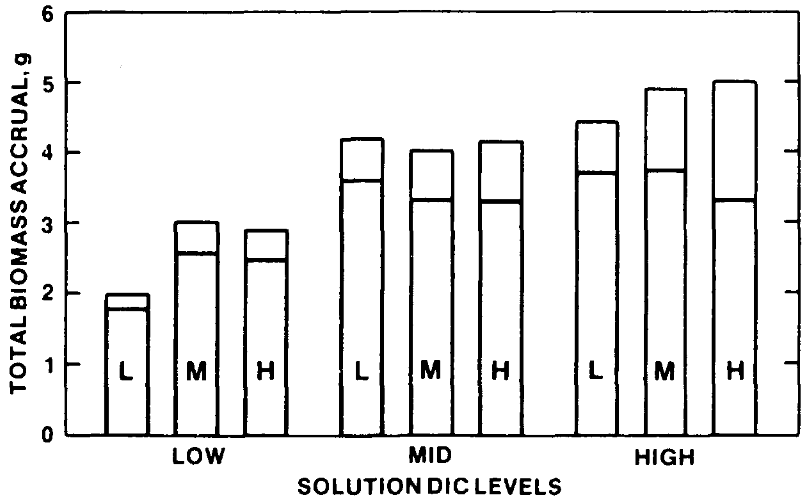


Figure 1. Total biomass accrual of *M. spicatum* in relation to inorganic carbon (DIC) and cation levels. Cation levels (L = low, M = mid, and H = high) are listed in Table 1. Shaded portions represent ash-free biomass and open portions represent ash mass

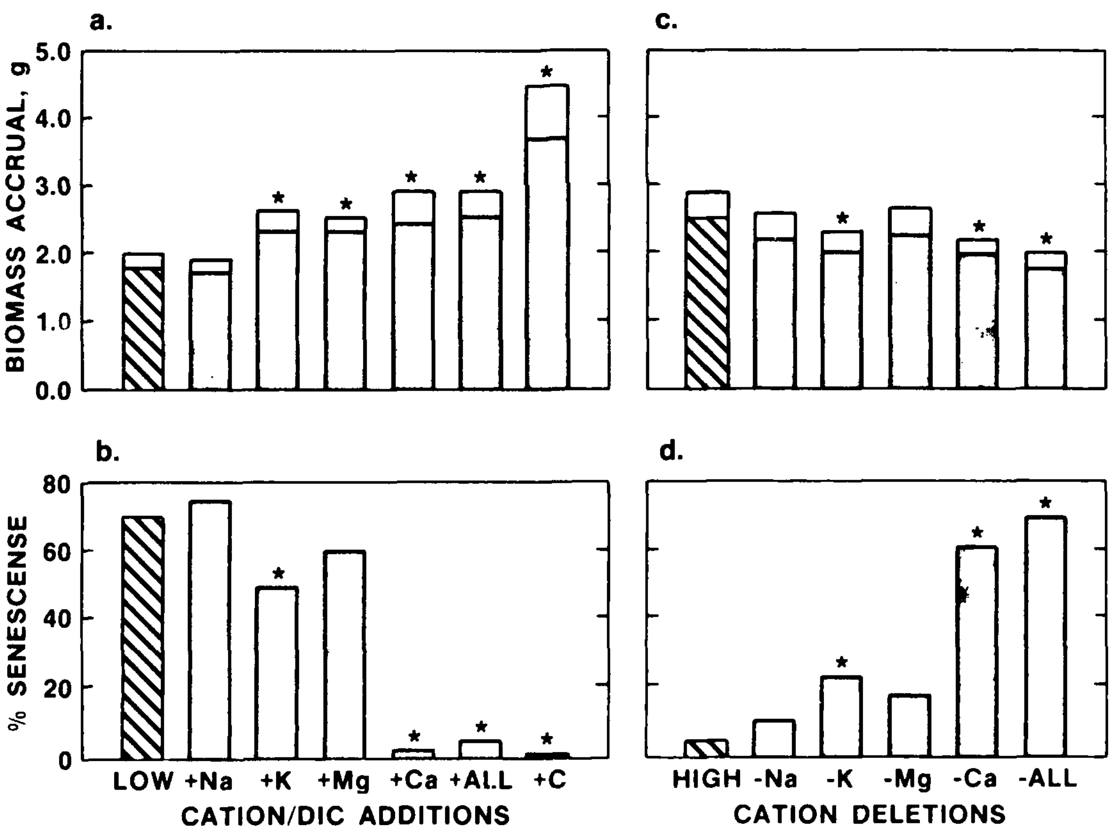


Figure 2. Biomass accrual and senescence of *M. spicatum* in relation to independent addition of specific cations and inorganic carbon to low carbon, low cation solution (a, b) and in relation to independent deletion of specific cations from low carbon, high cation solution (c, d). Shaded portions represent ash-free biomass and open portions represent ash mass. Asterisks denote significant differences between treatment and control (hatched bars). Significance was determined by Dunnett's procedure ($\alpha < 0.05$)

ONGOING AND FUTURE RESEARCH

The nature of the response of *M. spicatum* to carbon availability suggests that there is a certain critical level of DIC (between 3.5 and 10.5 mg C/l) required for normal growth and metabolism. Additional information is required to further illucidate the role of C availability on the growth of *M. spicatum*. Toward this end we are conducting studies on the effects of cation and inorganic C levels on photosynthesis and growth. In addition we are conducting detailed studies on the effects of C availability on the growth of *M. spicatum*. The studies will involve an assessment of the relative importance of various sources of inorganic C in supporting problem levels of *M. spicatum*. Inorganic C sources include: (1) atmospheric exchange of CO_2, (2) bicarbonate supplied by the dissolved inorganic carbon (DIC) pool of the water column, and (3) CO_2 supplied by heterotrophic respiration.

Upon completion of the experimentation with *M. spicatum*, we plan to continue similar studies with additional introduced and native species of submersed aquatic plants (*Hydrilla*, *Egeria*, and *Potamogeton*). These studies should help to identify possible competitive relationships (with respect to water chemistry) among introduced and native species, thereby resulting in an increased understanding of successional processes operating in submersed macrophyte communities. Increased knowledge of these processes is a necessary prerequisite for successful aquatic plant management.

ACKNOWLEDGEMENTS

We gratefully acknowledge the diligent efforts of D. J. Bates, S. M. Hennington, D. G. McFarland, and R. H. Warren.

REFERENCES

Barko, J. W. 1982. "Influence of Potassium Source (Sediment vs. Open Water) and Sediment Composition on the Growth and Nutrition of a Submersed Freshwater Macrophyte (*Hydrilla verticillata* (c.f.) Royle)," *Aquatic Botany*, Vol 12, pp 157-172.

Barko, J. W. 1983. "The Growth of *Myriophyllum spicatum* L. in Relation to Selected Characteristics of Sediment and Solution," *Aquatic Botany*, Vol 15, pp 91-103.

Barko, J. W., and Filbin, G. J. 1983. "Influences of Light and Temperature on Chlorophyll Composition in Submersed Freshwater Macrophytes," *Aquatic Botany*, Vol 15, pp 249-255.

Barko, J. W., and Smart, R. M. 1981. "Comparative Influences of Light and Temperature on the Growth and Metabolism of Selected Submersed Freshwater Macrophytes," *Ecological Monographs*, Vol 51, No. 2, pp 219-235.

Barko, J. W., and Smart, R. M. 1983. "Effects of Organic Matter Additions to Sediment on the Growth of Aquatic Plants," *Journal of Ecology*, Vol 71, pp 161-175.

Barko, J. W., and Smart, R. M. 1984. See pp 140-147 of this proceedings.

Barko, J. W., Hardin, D. G., and Matthews, M. S. 1982. "Growth and Morphology of Submersed Freshwater Macrophytes in Relation to Light and Temperature," *Canadian Journal of Botany*, Vol 60, pp 877-887.

Hellquist, C. B. 1980. "Correlation of Alkalinity and the Distribution of *Potamogeton* in New England," *Rhodora*, Vol 82, pp 331-344.

Hutchinson, G. E. 1957. *A Treatise on Limnology*, Vol 1, John Wiley and Sons, New York.

Hutchinson, G. E. 1970. "The Chemical Ecology of Three Species of *Myriophyllum* (Angiospermae, Haloragaceae)," *Limnology and Oceanography*, Vol 15, pp 1-5.

Kadono, Y. 1982. "Occurrence of Aquatic Macrophytes in Relation to pH, Alkalinity, Ca^{++}, Cl^{-}, and Conductivity," *Japanese Journal of Ecology*, Vol 32, pp 39-44.

Lowenhaupt, B. 1956. "The Transport of Calcium and Other Cations in Submerged Aquatic Plants," *Biological Review*, Vol 31, pp 371-395.

Lucas, W. J., and Dainty, J. 1977. "HCO_3^- Influx Across the Plasmalemma of *Chara corallina:* Divalent Cation Requirement," *Plant Physiology*, Vol 60, pp 862-867.

Moyle, J. B. 1945. "Some Chemical Factors Influencing the Distribution of Aquatic Plants in Minnesota," *American Midland Naturalist*, Vol 34, pp 402-420.

Seddon, B. 1972. "Aquatic Macrophytes as Limnological Indicators," *Freshwater Biology*, Vol 2, pp 107-130.

Spence, D. H. N. 1967. "Factors Controlling the Distribution of Freshwater Macrophytes with Particular Reference to the Lochs of Scotland," *Journal of Ecology*, Vol 55, pp 147-170.

AD-P003 613

THE "CAROLINA SESSION"

Growth, Reproduction, and Biomass of Hydrilla in North Carolina

by
Steve M. Harlan,* Graham J. Davis,* and George Pesacreta**

INTRODUCTION

Hydrilla (*Hydrilla verticillata* (L. fil.) Royle) is a noxious submersed aquatic weed which was introduced into the United States in Florida around 1960 (Haller 1978). Since its introduction, hydrilla has spread as far north as Delaware (Joe Joyce, personal communication) and as far west as California (Yeo and McHenry 1977). Based on its distribution in Europe (Cook and Luond 1982), the range of hydrilla could potentially extend into Canada.

Certain morphological and physiological characteristics are associated with the phenomenal ability of hydrilla to invade an aquatic system, overtop more desirable native rooted aquatic species, and form very dense monospecific mats. One of these adaptations is the formation of tubers which are vegetative propagules formed at the ends of positively geotropic rhizomes (Van, Haller, and Garrard 1978). Tubers develop in the hydrosoil and thus are very resistant to all control methods. Also, hydrilla's ability to become established and photosynthesize under low light intensities is unequaled by any other submersed rooted aquatic macrophyte (Van, Haller, and Bowes 1976).

Hydrilla can adversely affect the normal use of an infested system as swimming, fishing, boating, and other water-based activities can become impossible or, at best, difficult. Further, mosquito populations can increase due to stagnation of the infested water body and gamefish populations can be stunted because forage fish are lost in the dense plant growth.

Hydrilla growing in lakes in Umstead State Park in North Carolina was first identified by William Haller in 1981 and had apparently been established in the area for several years. Since its initial identification, hydrilla has been found in 18 other water bodies, all in Wake County. Hydrilla has the potential to become a very serious problem as there are presently no effective means of halting its spread or eradicating it after infestation occurs.

For effective management in North Carolina, knowledge of the growth, reproduction, and biomass of hydrilla in North Carolina is needed. This research addresses these questions.

* Department of Biology, East Carolina University, Greenville, North Carolina.
** Department of Zoology, North Carolina State University, Raleigh, North Carolina.

MATERIALS AND METHODS

Biomass sampling

Two annual biomass surveys were conducted for three study lakes (Lake Anne (5.9 ha), Big Lake (23.7 ha), and Lake Wheeler (200.1 ha)) to determine the total of standing crop biomass in each lake. The first annual biomass survey was in July and August 1982 and the second annual biomass survey was in July and August 1983.

The survey biomass estimates were determined from sample areas representative of all reaches of a given lake. Random samples were taken either from a predetermined bed area at an intermediate depth parallel to the shoreline or along transects perpendicular to the shoreline, depending on the size and homogeneity of the area being sampled. Biomass samples were taken with 0.1- by 0.1-m or 0.5- by 0.5-m quadrat frames, washed in the field, sealed in plastic bags, stored in the shade, and returned to the laboratory for processing the same day. In the laboratory, the samples were sorted by species, rewashed, and spun to no runoff in a commercial clothes washer. Wet weights were determined; aliquots of each sample were dryed in a forced-draft oven for 24 hr at 85°C, allowed to cool to room temperature in a desiccator, and weighed to calculate percent dry weight. Dry weights are reported as grams dry weight per square metre ± standard error of the mean.

To determine seasonal variations in biomass, samples were collected monthly from a study plot established in each lake. Sampling for seasonal variation began in September 1982 and continued for 1 year. Each study plot was within a 1 ± 0.1 m depth contour in an area of dense plant growth and was large enough to minimize the variation between biomass samples due to removal of plant material. Five replicate samples were collected from each study plot. Processing of the plants in the laboratory was the same as for the annual biomass survey samples.

Bed areas were determined either by measuring the dimensions of the beds onsite or by planimetry based on field measurements of bed areas sketched on a U.S. Geological Survey (USGS) map of the lake. Total surface areas of each study lake were determined by planimetric measurements of USGS maps and aerial photographs obtained from the North Carolina Department of Transportation.

Tuber studies

Monthly samples of tubers were taken along the margins of each study plot. Samples were collected with a corer designed after the Sutton core sampler (Sutton 1982). The corer was constructed from metal electrical conduit pipe (10.2 cm in diameter) with a serrated cutting edge and a push rod for extruding the cores. The clay and coarse detrital sediments present remained in the corer without an applied vacuum. Cores were taken to a depth of 20 cm below the hydrosoil surface. Ten samples were taken from each lake at equal intervals beginning at a random starting point. Samples were washed in the field in ambient water in 0.75-mm mesh bags, and the tubers were counted and stored in ambient water. Five of the ten samples were sliced into four subsections from 0 to 8 cm, 8 to 12 cm, 12 to 16 cm, and 16 to 20 cm to determine tuber density

distribution within each core. Tuber density estimates were reported as the number of tubers/m² within the 1.0-m depth contour of the study lakes and are taken to be maximum values for tuber density.

Tubers were transported to East Carolina University within 36 hr where viability was inferred from germination experiments in the laboratory. Tubers were incubated in deionized water for 14 days at 26°C in the dark and the average percent germination determined. Tuber germination was determined for each subsection separately and no less than three replicates containing 20 tubers each were used for each lake.

RESULTS AND DISCUSSION

Biomass

Growth of hydrilla in North Carolina began from tubers and turions in late March to mid-April and reached peak standing crop biomass in September. Plant beds began breaking up in October and by late December standing crop and fragmented biomass were negligible (Figure 1). Thus, in North Carolina plant beds did not overwinter.

Biomass estimates for the surveys of the three study lakes varied considerably when extrapolated to the total surface area (Table 1). Biomass was directly proportional to the percent of the total lake surface overlying 2.0 to 3.0 m of water depth or less, rather than lake size. Virtually all biomass production occurred in this depth range. In clear waters hydrilla can grow to depths of as great as 7.0 m

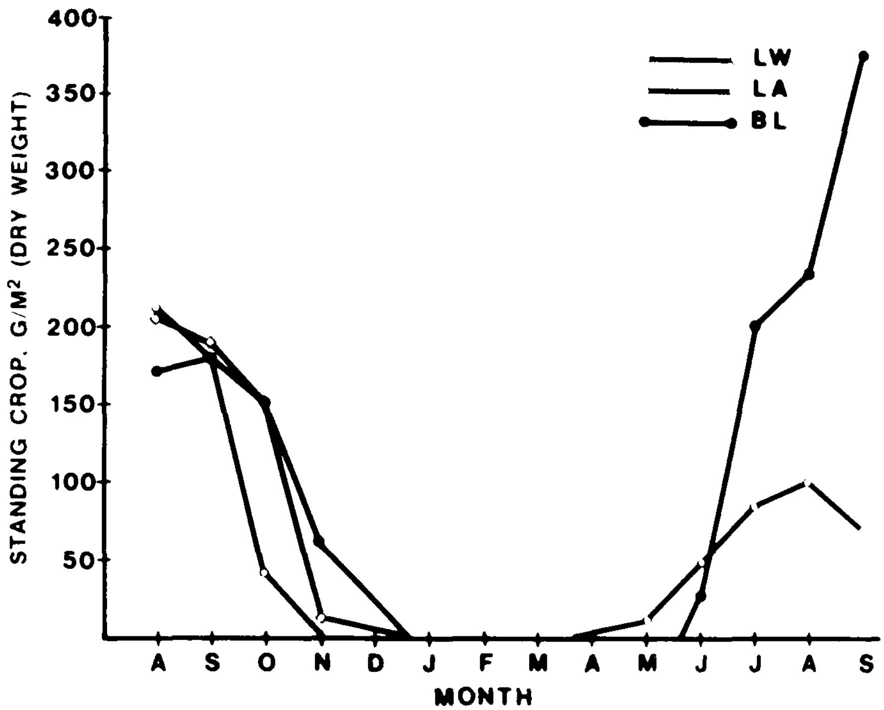


Figure 1. A comparison of seasonal variations in biomass in three North Carolina lakes (LW = Lake Wheeler, LA = Lake Anne, BL = Big Lake)

Table 1

A Comparison of Hydrilla Biomass and Bed Areas for Three North Carolina Lakes in 1982 and 1983

Parameter	*Big Lake*		*Lake Anne*		*Lake Wheeler*	
	1982	*1983*	*1982*	*1983*	*1982*	*1983*
Biomass, kg	12,406.7	15,155.3	2,349.9	2,867.6	15,625.8	13,059.0
Biomass, g/m^2	52.3	63.8	39.8	44.7	7.8	7.0
Percent cover	—	37.7	24.2	31.3	13.9	12.7
Percent increase, g/m^2	—	18.0	–	11.0	–	-10.3
Percent increase (bed area)	—	14.3	—	22.7	—	-14.7

Note: Statistics are omitted from these data because total standing crop biomass estimates are based on the totals of several different bed areas in each lake for which the statistics were calculated separately.

(Cook and Luond 1982). Thus, the depth of significant biomass production in North Carolina is probably limited over the long term (years) by turbidity. Secchi depths were mostly 1.3 to 1.7 m for Lake Wheeler and 1.0 to 1.3 m for Big Lake and Lake Anne. Generally, plants grew in Lake Wheeler 0.5 m deeper than either Big Lake or Lake Anne. Biomass distribution patterns would be expected to adjust to changes in seasonal turbidity patterns or water depth fluctuations with respect to the presently maintained depth.

September biomass estimates for the three study plots in 1982 were similar: Big Lake, 181.5 ± 20.0 g/m^2; Lake Anne, 178.2 ± 20.2 g/m^2; Lake Wheeler, 182.5 ± 24.0 g/m^2. The estimates for September 1983 were: Big Lake, 374.0 ± 20.7 g/m^2; Lake Anne, 73.1 ± 23.5 g/m^2; Lake Wheeler, no samples taken. Biomass for Big Lake is compared with similar estimates for Florida in Table 2. The lower biomass for the Lake Anne study plot in 1983 was related to herbicide effects and is not representative of the biomass present in other reaches of the lake. Biomass sampling of the Lake Wheeler study plot was not conducted in 1983 because the

Table 2

Some Maximal Seasonal Biomasses for Hydrilla in Florida as Compared to That in North Carolina

Water Body	*Month*	*Year*	*Biomass, g/m^2*	*Citation*
Southern canals	—	1964	242	Blackburn, White, and Weldon (1968)
Lake Jackson (northern)	November	1977	240	Bowes, Holaday, and Haller (1979)
Orange Lake (central)	November	1977	240	Bowes, Holaday, and Haller (1979)
Lake Trafford (southern)	August	1977	890	Bowes, Holaday, and Haller (1979)
Little Lake Burton	October	1976	300	Osborn and Sassic (1981)
Lake Baldwin	August	1978	622	Maceina and Shireman (1980)
Lake Conway (west pool)	July	1977	155	Nall and Shardt (1978)
Big Lake (study plot)	September	1982	182	This study
Big Lake (study plot)	September	1983	374	This study

Note: Dry weights for this study are based on 7.0 percent of wet weight. Otherwise, except for the study of Bowes, Holaday, and Haller (1979), dry weights were calculated as 10 percent of wet weight. This figure varies from 5 percent or less (Haller 1978) to 13.5 percent (Boyd and Blackburn 1970). Dry weight as percent of wet weight of hydrilla in Lake Conway is only for quadrats with hydrilla. Lake Conway had mixed communities at the time of the study and hydrilla was not a serious problem. For all studies except for that of Bowes, Holaday, and Haller (1979), biomass is actually standing crop. Belowground biomass of hydrilla is relatively small. Root-to-shoot ratios in the experiments of Barko and Smart (1980) were around 0.05; ratios of plants growing in earthern ponds were 0.14 (Haller and Sutton 1975).

lake was drawn down 1.3 m for repairs to the dam. Seasonal biomass trends in Lakes Anne and Wheeler may have followed those in Big Lake in 1983 (Figure 1) were it not for the herbicide effects and the drawdown.

Hydrilla usually occurs in dense monospecific mats. This was true for both Big Lake and Lake Anne, but in Lake Wheeler two other rooted macrophytes grew in association with hydrilla in the shallower areas. These were *Eleocharis acicularis* (dwarf spikerush) and *Najas minor* (bushy pondweed). After Lake Wheeler was drawn down, plant beds from the shoreline to a depth of 1.3 m were killed. As a result, both *Najas* and *Eleocharis* were essentially eliminated from the plant community for 1983.

The biomass estimates of the surveys reflect an increase in both plant bed area and biomass for Lake Anne and Big Lake, but a decrease for the same parameters in Lake Wheeler (Table 1). The decreases in Lake Wheeler were the result of the drawdown in 1983 which caused a loss of 12.4 ha of the surface area of the lake. Of this loss, approximately 70 percent was previously colonized by hydrilla. Most of the northwest end of Lake Wheeler where hydrilla was not established in 1982 because of water depth is now less than or equal to the 3.0-m limiting depth for hydrilla. The 1983 biomass survey of Lake Wheeler showed that hydrilla beds were rapidly increasing in size in this area.

Reproduction

Reproduction of hydrilla in North Carolina occurs by four means: tubers, turions, plant fragments, and stolons.

In North Carolina tuber germination began in March and continued through August and tuber formation began in June and continued through October. Tuber germination in North Carolina appeared to be initiated by increasing water temperature and occurred when the temperature was 11° to 13°C. Maximum tuber densities for the three study plots in March 1983 ranged from 703 tubers/m^2 in Big Lake to 1312 tuber/m^2 in Lake Anne (Figure 2). Minimum tuber densities occurred in all three study plots in July 1983 (Figure 2).

Tuber germination experiments indicated little seasonality because greater than 85 percent, and frequently 95 to 100 percent, germination occurred in the laboratory. Tubers did not germinate in the plant beds in late August when the water temperature was 26°C, well above the minimum temperature for germination found in this study and also that reported for Florida (Haller, Miller, and Garrard 1976). Processed tuber samples left in the lakes on the surface of the hydrosoil germinated when tubers were dormant elsewhere in the lakes, but tubers in intact cores brought back to the laboratory in polyvinyl chloride collars and incubated at that time did not germinate. As usual, processed tubers germinated in the laboratory; thus, processing breaks dormancy.

Tuber formation occurs below the surface of the hydrosoil and generally tubers were not found in any significant numbers below 10 cm. Tubers do not fully mature until after abscission from the rhizome and only fully mature tubers will germinate. Abscission of tubers begins approximately 3 to 4 weeks after formation is noted.

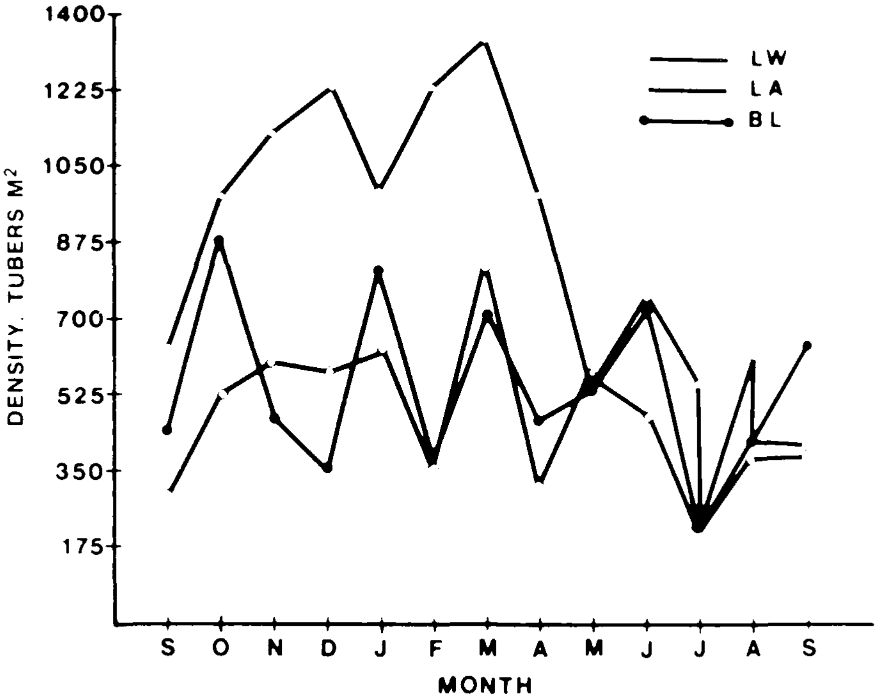


Figure 2. A comparison of seasonal variations in tuber densities in three North Carolina lakes

Given the phenology of tuber formation and germination, and the fact that few tubers germinate in the lakes until the spring after formation, it can be inferred that a significant number of tubers would be available for regrowth the following spring (Figure 2, July), even if all plants were killed following tuber germination and prior to tuber abscission. Also, it is thought that tubers can remain viable for up to 10 years in the hydrosoil (Haller, personal communication, in Nall and Schardt 1978); this could be an additional management problem.

Turions are overwintering propagules and are very similar in function to tubers. Turion formation began in October and continued through December. Turion densities were low compared to tuber densities. Estimates of turion density for March 1983 ranged from $40/m^2$ for Big Lake to $10/m^2$ for Lake Anne within the study plots. Turion germination appeared to begin before tuber germination but this varied between lakes. Also, turions usually did not germinate in the laboratory when they did not naturally germinate in the field and thus processing does not appear to break dormancy in turions as in tubers.

Turions are formed in the leaf axils or at the apices of axillary branches in proximity to the meristem of floating plant fragments present when the plant beds begin to break up in the fall. At maturity (3 to 4 weeks after formation is noted) they abscise and fall to the surface of the hydrosoil. In the late fall plant fragments were usually rafted to near the shore; therefore, it would be expected that turion densities are greatest near the shore. This is supported by the fact that turions were found germinating in the spring in greatest numbers close to the shore.

Plant fragments are the most likely means of spread to other water bodies. Adventitious root formation in floating plant fragments results in anchorage of the plants in shallow water. These roots may grow to approximately 1.0 m and such root growth may play a part in plant establishment. Plant fragmentation is greatly facilitated by recreational use of an affected water body. Plant fragments caught in boat propellers or on boat trailers are transported to other systems. Reproduction from plant fragments is only possible during the growing season because neither plant beds nor plant fragments overwinter in North Carolina. For this same reason, stoloniferous growth would only be a problem during the growing season.

Regrowth of hydrilla in North Carolina is dependent on tuber and turion germination in the spring. In a previously infested system, tuber germination is the primary means for reestablishment of the plant beds, but in other systems turions formed in the late fall on floating plant fragments could be of significance.

Hydrilla produces both male and female flowers in North Carolina and the plants appear to be monoecious. Flower production appeared to coincide with tuber formation as it began in June and continued through October. Estimates for mature male flower densities (i.e. those found floating on the water surface) for September 1983 were $70/m^2$ for Lake Anne and $130/m^2$ for Big Lake, but this varied considerably and ranged from 55 to $310/m^2$ in Big Lake. Female flower densities for the same period were approximately $140/m^2$ for Lake Anne and $165/m^2$ for Big Lake. Production of both male and female flowers in North Carolina gives the potential for seed production with increased genetic variability. However, to date no seeds or seedlings have been found, but pollen is being released. This should be a topic for further research.

ACKNOWLEDGEMENTS

This research was supported in part by the U.S. Department of Interior through the Water Resources Research Institute of the University of North Carolina and the city of Raleigh.

REFERENCES

Barko, J. W., and Smart, R. M. 1980. "Mobilization of Sediment Phospherus by Submersed Freshwater Macrophytes," *Freshwater Biology*, Vol 10, pp 229-238.

Blackburn, R. D., White, P. F., and Weldon, L. W. 1968. "Ecology of Submersed Aquatic Weeds in South Florida Canals," *Weed Science*, Vol 16, pp 261-265.

Bowes, G., Holaday, A. S., and Haller, W. T. 1979. "Seasonal Variation in the Biomass, Tuber Density, and Photosynthetic Metabolism of Hydrilla in Three Florida Lakes," *Journal of Aquatic Plant Management*, Vol 17, pp 61-65.

Boyd, C. E., and Blackburn, R. D. 1970. "Changes in the Proximate Composition of Some Common Aquatic Weeds," *Hyacinth Control Journal*, Vol 8, pp 42-44.

Cook, C. D. K., and Luond, R. 1982. "A Revision of the Genus *Hydrilla* (Hydrocharitaceae)," *Aquatic Botany*, Vol 13, pp 485-564.

Haller, W. T. 1978. "Hydrilla: A New and Rapidly Spreading Aquatic Weed Problem," Agricultural Experiment Station, Institute of Food and Agricultural Sciences, University of Florida, Gainesville.

Haller, W. T., and Sutton, D. L. 1975. "Community Structure and Competition Between Hydrilla and Vallisneria," *Hyacinth Control Journal*, Vol 13, pp 48-50.

Haller, W. T., Miller, J. L., and Garrard, L. A. 1976. "Seasonal Production and Germination of Hydrilla Vegetative Propagules," *Journal of Aquatic Plant Management*, Vol 14, pp 26-29.

Maceina, M. J., and Shireman, J. V. 1980. "Recording Fathometer Techniques for Determining Distribution and Biomass of *Hydrilla verticillata* Royle," Miscellaneous Paper A-80-5, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Nall, L. E., and Schardt, J. D. 1978. "The Aquatic Macrophytes of Lake Conway, Florida; Vol 1, Large-Scale Operations Management Test of Use of the White Amur for Control of Problem Aquatic Plants: Report 1, Baseline Studies," Technical Report A-78-2, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Osborne, J. A., and Sassic, N. M. 1981. "The Size of Grass Carp as a Factor in the Control of Hydrilla," *Aquatic Botany*, Vol 11, pp 129-136.

Sutton, D. L. 1982. "A Core Sampler for Collecting Hydrilla Propagules," *Journal of Aquatic Plant Management*, Vol 20, pp 57-59.

Van, T. K., Haller, W. T., and Bowes, G. 1976. "Comparison of the Photosynthetic Characteristics of Three Submersed Aquatic Plants," *Plant Physiology*, Vol 58, pp 761-768.

Van, T. K., Haller, W. T., and Garrard, L. A. 1978. "The Effect of Daylength and Temperature on Hydrilla Growth and Tuber Production," *Journal of Aquatic Plant Management*, Vol 16, pp 57-59.

Yeo, R. R., and McHenry, W. B. 1977. "*Hydrilla*, A New Noxious Aquatic Weed in California," *California Agriculture*, Vol 31, pp 4-5.

THE "CAROLINA" SESSION

Hydrilla Management in North Carolina

by

R. G. Hodson,* G. J. Pesacreta,* F. R. Tarver III,*
K. A. Langeland,** D. J. Demont,* and M. T. Huish*

BACKGROUND

Hydrilla (*Hydrilla verticillata* Royle), an aquatic macrophyte which is a major problem in several southeastern states, now presents a serious threat to North Carolina waters. Water resource managers are concerned about this plant because it causes a variety of problems. Recreational use of lakes infested with hydrilla is reduced because boating, swimming, and fishing activities are greatly curtailed. Agricultural uses of water for irrigation may be impacted by hydrilla because hydrilla reduces water flow and water availability. Other users requiring large volumes of water, such as city water supply systems and once-through cooling systems for power plants, may be impacted by reduced water flow and water availability.

A survey conducted by the North Carolina Department of Agriculture in 1981 found 13 lakes and ponds infested with hydrilla (Rhodes 1982). These sites were all within a 40-km radius of Raleigh, N.C., and included three lakes in William B. Umstead Park and Lakes Wheeler, Benson, and Raleigh water supply reservoirs for Raleigh, N.C. Although three drainage systems were surveyed, the Neuse, Cape Fear, and Roanoke Rivers, only the Neuse River drainage contained sites infested with hydrilla. Since that survey a small hydrilla infestation was found in Lake Hyco on the Roanoke River drainage.

This situation is a serious threat to two large reservoirs recently completed in North Carolina. Falls of the Neuse Reservoir, a 12,500-acre impoundment north of Raleigh, will soon serve as the main source of water for the City of Raleigh. This reservoir is in the Neuse River drainage very near several sites infested with hydrilla. B. Everett Jordan Reservoir (13,900 acres) southwest of Raleigh is in the Cape Fear River drainage, but is also located in close proximity to several sites infested with hydrilla. Both of these reservoirs have large areas of rather shallow water where hydrilla would flourish if it invaded the lakes.

Water resource managers are concerned because hydrilla spreads rapidly and is difficult to control. The plant grows at low light intensities and can invade lakes and spread rapidly even when established stands of other macrophytes already exist (Van, Haller, and Bowes 1976; Van et al. 1977). The ability to grow at low light intensities enables hydrilla to out-compete other species during regrowth from the hydrosoil (Bowes et al. 1977). Once a hydrilla canopy forms at the surface, reduced light penetration to other species retards their growth (Haller and Sutton 1975).

* Zoology Department, North Carolina State University, Raleigh, North Carolina
** Crop Science Department, North Carolina State University, Raleigh, North Carolina

Controlling or managing hydrilla is difficult because the plant has several means of asexual reproduction. Tubers, which form terminally on rhizomes in the hydrosoil, probably are the most important means of asexual reproduction. This structure resists adverse environmental conditions such as freezing, desiccation, and herbicides. Turions form in the leaf axils separate from the plant and sink to the hydrosoil. When tubers or turions sprout, a new plant is formed. Stem fragments containing one node are capable of developing vegetative buds which produce new plants (Langeland and Sutton 1980).

Sexual reproduction of hydrilla was thought not to occur in the United States because only pistillate flowers had been found. However, staminate flowers were discovered at all the study sites in North Carolina in 1983 (Harlen, Davis, and Pesacreta, manuscript) and seeds have been found in experimental pools in California (R. A. Yeo, personal communication) and Florida (T. K. Van, personal communication). If seed production occurs in North Carolina, then the ability of hydrilla to spread to other lakes will be greatly increased.

The purpose of this paper is to present the results of hydrilla control studies conducted in North Carolina. The work concentrated on biological and chemical control methods because they have provided effective control in other states. Results presented here are not final since follow-up evaluations of some treatments will not be completed until fall 1984.

METHODS

Seven of the hydrilla-infested sites in Wake County were selected as study sites. These sites were used to evaluate biological and chemical methods of controlling hydrilla and to study the biology of hydrilla.

Biomass samples were collected monthly from study plots located in well-established hydrilla mats at 1 m depth. Each study plot was divided into grids and sample quadrats were chosen randomly. Three to fifteen quadrats were sampled in each study plot by removing all attached plant material within either a 0.1 or 0.5 m quadrat. Samples were washed in mesh bags, separated by species, spun to no runoff, and dried in a force draft oven at 85° C for 24 hr and weighed.

A recording fathometer was used to evaluate hydrilla density. Transects were run perpendicular to the shoreline through the center of each study plot. The percent cross-sectional area coverage was calculated planimetrically to the 2.5-m-depth contour (Maceina and Shireman 1980).

Biological and chemical control methods which were successful in other states were chosen for evaluation of hydrilla control in North Carolina (Table 1). Winter drawdown was also evaluated.

Biological control methods consisted of stocking herbivorous fish, grass carp (*Ctenopharyngodon idella*) and redbelly tilapia (*Tilapia zilli*). The number of fish stocked was based on the area infested with hydrilla (Terrell and Terrell 1975). Grass carp were stocked in two sites at 50/ha. Upchurch Pond was stocked with grass carp in late March 1983 except for a small enclosed area to serve as a check. Ten grass carp were released into a 0.2-ha enclosure in Lake Anne in mid-June

Table 1

Control Methods, Location, Date, Application Rates, and Area Treated (hectares) for Hydrilla in North Carolina

Herbicide Formulation	*Location*	*Date Applied*	*Rate*	*Area Treated, ha*
Aquathol K	Lake Anne	Jun 83	56	0.20
Aquathol K	Lake Anne	Sep 83	56	0.20
Aquathol K	Reedy Creek	Jun 83	56	0.81
Aquathol K	Reedy Creek	Aug 83	56	0.40
Diquat + Cutrine	Lake Anne	Jun 83	18.7 + 18.7	0.20
Diquat + Cutrine	Reedy Creek	Jun 83	18.7 + 18.7	0.40
Diquat + Cutrine	Reedy Creek	Aug 83	18.7 + 18.7	0.20
Diquat	Lake Anne	Jun 83	18.7	0.10
Diquat	Lake Anne	Sep 83	18.7	0.60
Cutrine	Reedy Creek	Jun 83	84	0.40
Sonar	Big Lake	Sep 83	4.7	4.0
Fenatrol	Sycamore	Dec 83	122	2.0
Biological Treatment	***Location***	***Date Stocked***	***Rate, fish ha***	***Area Treated, ha***
Tilapia*	Lake Anne	Jun 83	2800	0.0024
Tilapia	Lake Anne	Jun 83	300	0.15
Grass carp**	Lake Anne	Jun 83	50	0.12
Grass carp	Upchurch Pond	Mar 83	50	1.2
Grass carp	Rhudy Pond	Oct 82	200	0.01

* *Tilapia zilli.*

** *Ctenopharyngodon idella.*

1983. Nearby hydrilla beds served as checks. Rhudy Pond was stocked with two grass carp, a rate of 200/ha, in October 1982.

All tilapia stockings were made in mid-June 1983 into enclosures located in Lake Anne. Two enclosures, 0.024 and 0.029 ha, were stocked at a rate of 700/ha and three circular pens were stocked at a rate of 2800/ha. Hydrilla beds in surrounding areas served as checks.

Herbicide treatments consisted of early summer and early fall applications of diquat, diquat plus copper (Cutrine), endotholl (Aquathol K), and fluridone (Sonar). The herbicides were applied just below the surface in combination with a polymer. An airboat-mounted sprayer and a hand-gun sprayer were used to apply the chemicals. A drawdown application of fenac (Fenatrol) was made in Sycamore Lake in December 1983, too late for the evaluation to be presented in this report. The fluridone application was not made until September 1983 and will be evaluated during the 1984 growing season.

Lake Anne was drawn down from October 1982 to February 1983 to determine if wintertime desiccation of tubers in the hydrosoil could be an effective hydrilla control treatment in North Carolina. Soil moisture content and percent tuber germinations were checked monthly. Triplicate sediment cores were collected with polyvinyl chloride core liners and sealed at both ends with stoppers. Sediment cores were sliced into 4-cm sections, homogenized, subsampled, and desiccated at 80°C for 24 hr. Tubers from each 4-cm section were incubated in the dark at 26°C for 2 weeks and sprouting was monitored.

RESULTS AND DISCUSSION

Biological control

Grass carp successfully controlled hydrilla when stocked at 50/ha or more during the winter or spring before hydrilla began to grow. Under these circumstances hydrilla was controlled in one growing season. Upchurch and Rhudy Ponds were stocked in early 1983 and late 1982, respectively. By September 1983, the month of maximum hydrilla bior ass production in area lakes (G. J. Davis, personal communication), measurable biomass could not be found in either pond (Table 2). The check area in Upchurch Pond had 25 g/m^2 (dry weight) of hydrilla. Greater amounts of hydrilla biomass would usually be present in the check area but growth was reduced due to shallow water caused by a summer drought.

Grass carp stocked at 50/ha in June in Lake Anne did not eliminate hydrilla during the first year. Biomass values in the lake were nearly 152 g/m^2 (dry weight) before stocking and the grass carp consumption did not equal growth. However, biomass reductions of approximately 50 percent were achieved based on nearby check areas (Table 2). The unstocked areas had biomass values in September of nearly 100 g/m^2 (dry weight) compared to values near 50 g/m^2 (dry weight) in the stocked area. Thus, it appears that grass carp stocked during the summer may take two growing seasons to control hydrilla. It may also be that some of the grass carp escaped from the enclosure or died, thereby reducing the stocking density. This possibility will be checked during early 1984 when the lake is drawn down.

Recommended stocking rates for grass carp have ranged from 12 to 400 per hectare (Sutton 1977; Haller 1979; Miley, Leslie, and Van Dyke 1979). Although 50/ha is near the low end of the recommended stocking range, it seems reasonable that an even lower rate may be possible in North Carolina. Most research on grass carp was accomplished in Florida where hydrilla has a longer growing season and stocking rates around 50/ha have controlled hydrilla. In North Carolina where hydrilla biomass is nonexistent for approximately 6 months out of the year (G. J. Davis, personal communication), a lower stocking rate may be successful. Additional study is required to determine the optimum grass carp stocking rates for hydrilla control in North Carolina.

Table 2

Hydrilla Biomass Data from 1983 Herbivorous Fish Stockings; 1983 Control Plots and 1982 Prestocking Samples from Fish Treatment Areas*

Treatment	Stocking Rate (Date)	Prestocking Aug 82		Control Sep 83		Treatment Sep 83	
		$\overline{X}$ (N)	SD	$\overline{X}$ (N)	SD	$\overline{X}$ (N)	SD
Tilapia - L. Anne	2800/ha (Jun 83)			41 (4)	26		
Tilapia - L. Anne	2800/ha (Jun 83)			41 (4)	26	28 (3)	21
Tilapia - L. Anne	2800/ha (Jun 83)			41 (4)	26	83 (3)	40
Tilapia - L. Anne	700/ha (Jun 83)	241 (3)	50	140 (5)	41	50 (5)	18
Grass carp - L. Anne	50/ha (Jun 83)	152 (3)		95 (3)	25	49 (5)	56
Grass carp - Upchurch P.	50/ha (Mar 83)			25 (5)	11	0 (15)	
Grass carp - Rhudy P.	200/ha (Oct 82)			0 (5)			

* $\overline{X}$ = mean grams per square meter (dry weight); N = number of samples; SD = standard deviation.

The value of tilapia for hydrilla control in North Carolina is questionable at this time. Additional study is required to complete their evaluation. However, tilapia will probably not achieve control in 1 year as did grass carp. In the enclosures stocked with tilapia there was a general decrease in rooted biomass compared to check areas (Table 2). However, a substantial amount of unrooted biomass was present which gave the appearance of total coverage.

Apparently, tilapia consume the base of the hydrilla plant dislodging plant fragments which float to the surface. In a whole lake situation this may aid the spread of hydrilla because the plant fragments would drift with currents. In time, the plant fragments would develop adventitious roots and a new colony would be established. On the other hand, this feeding habit may interrupt tuber formation and the amount of hydrilla regrowth the following spring may be reduced. This situation will be evaluated in 1984.

There are other problems with using tilapia for aquatic weed control in North Carolina. Small tilapia (less than 92 mm) do not consume hydrilla stems. Large fish (over 150 mm) must be available if consumption of the stems is to be accomplished (Legner 1978). Tilapia are also a tropical species which die if exposed to temperatures below 10°C for a few days (Fitzpatrick et al. 1981). They cannot be stocked before hydrilla starts growing in the spring. No live tilapia were found in the enclosures after the water temperature dropped below 10°C. Although this situation could be beneficial for management of the species, the general problem associated with restocking each year could negate the positive aspects.

Chemical control

Except for the Aquathol K treatments in Reedy Creek Lake, herbicide treatments in 1983 were generally unsuccessful (Table 3). The treatment plot in Reedy Creek Lake where Aquathol K was so successful was a shallow area densely infested with hydrilla (Plot 3). This plot was heavily infested with hydrilla based on fathometer transects (Figure 1, Table 3). Because of the success of the June treatment, the plot was not retreated during August as were the other plots. Percent cross-sectional coverage was only 5 percent by mid-October.

Table 3
Percent Cross-Sectional Coverage by Hydrilla Along Fathometer Transects in Reedy Creek Lake Following Herbicide Treatment in 1983

		Percent Cross-Sectional Coverage to 2.5-m Contour					
		Summer Treatments			*Fall Treatments*		
Plot	*Herbicide (l/ha)*	*Jun* 27*	*Jul 17*	*Aug 4*	*Aug* 22*	*Sep 17*	*Oct 15*
1	Diquat + Cutrine (18.7 + 18.7)	18	7	15	26	23	44
2	Diquat + Cutrine (18.7 + 18.7)	45	16	30	77	49	73
3	Aquathol K (56)	88	6	1	1**	5	5
4	Aquathol K (56)	38	16	8	15	5	29
4	Cutrine (84)	41	13	25	62	61	74

* Treatment dates.

** Fall treatment not applied.

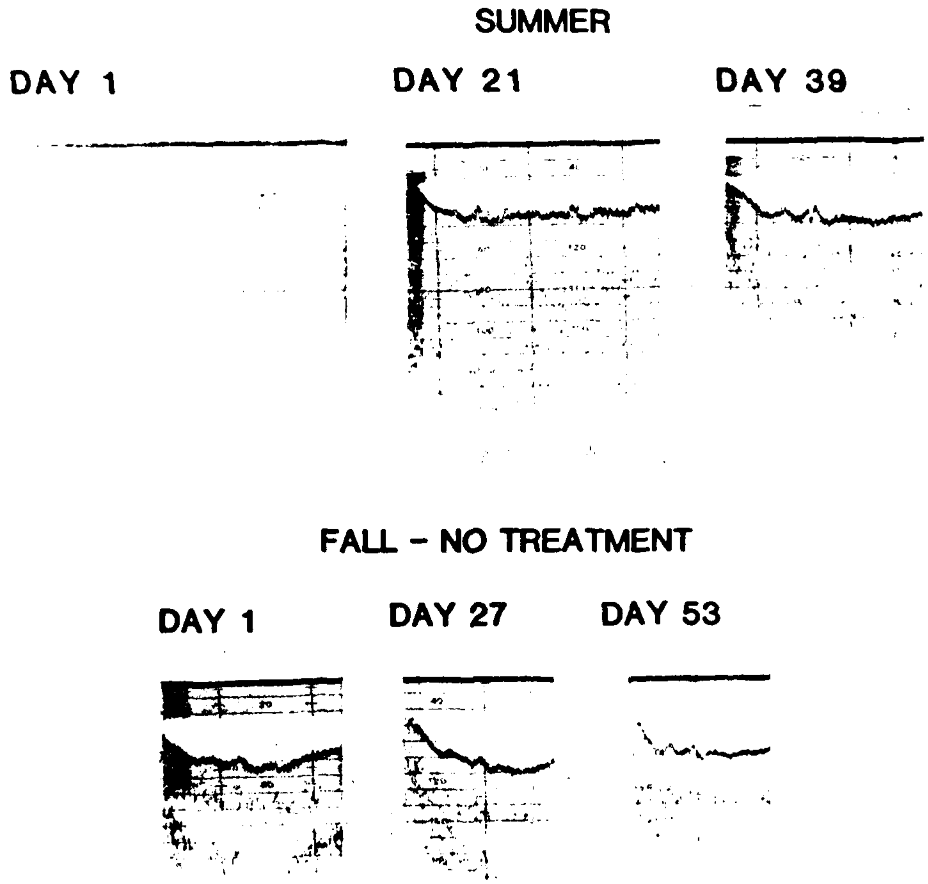


Figure 1. Fathometer tracings, Reedy Creek Lake, 1983 water column herbicide treatments, Aquathol K

The diquat plus cutrine and cutrine alone treatments in Reedy Creek Lake were temporarily successful. Reductions in percent cross-sectional coverage 21 days (17 July) after the 27 June 1983 treatment showed reductions of approximately one half to two thirds (Table 3). However, regrowth was rapid and by the time of the fall treatment (22 August), percent cross-sectional coverage was substantially higher than before treatment in June. These treatments may have been less successful than Aquathol K treatments because of differences in depth of the plots. The bottom of the plots receiving diquat plus cutrine had steep slopes as opposed to the gentle slope in the successful Aquathol K plot (Figure 2). In both the summer and fall treatments, the hydrilla in the deeper areas was only slightly affected and regrowth in those areas was rapid.

None of the herbicides was very effective in Lake Anne. Percent cross-sectional coverage was slightly reduced in all treatment plots 48 days after the summer treatment (Table 4). However, by the time of fall treatments (27 September),

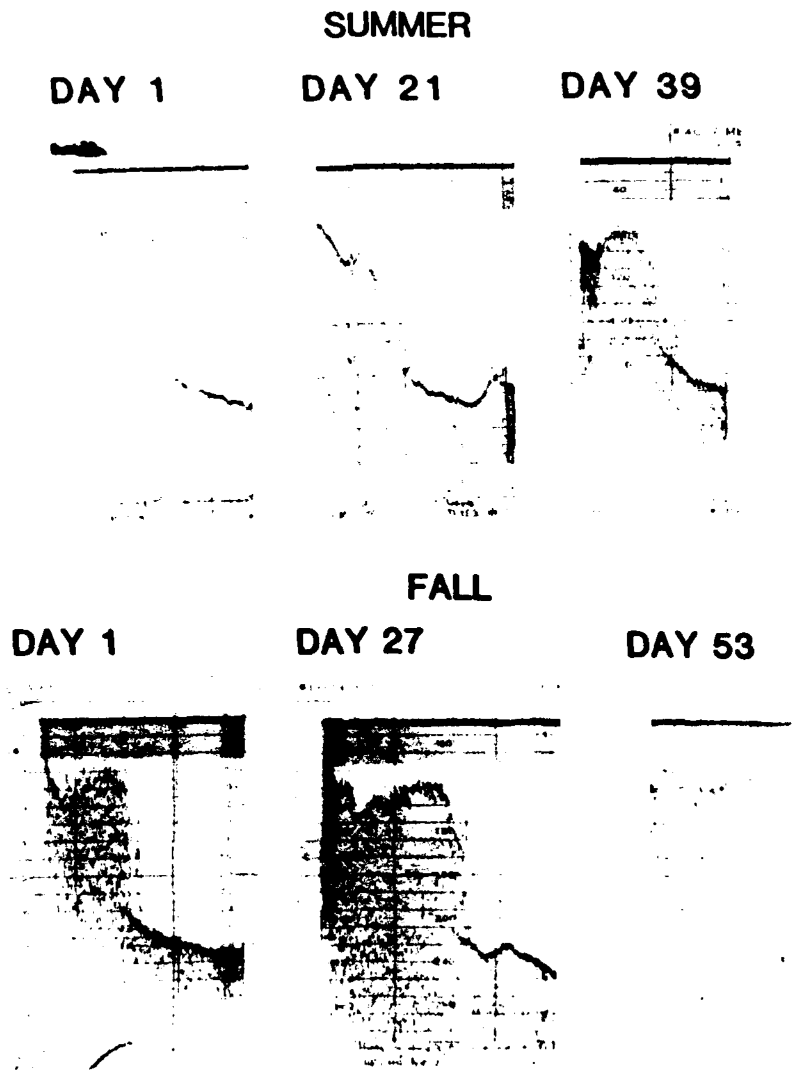


Figure 2. Fathometer tracings, Reedy Creek Lake, 1983 water column herbicide treatments, cutrine plus diquat

Table 4

Percent Cross-Sectional Hydrilla Coverage Along Fathometer Transects in Lake Anne Following Herbicide Treatments in 1983

		Percent Cross-Sectional Coverage to 2.5-m Contour					
		Summer Treatments				*Fall Treatments*	
Plot	*Herbicide (l/ha)*	*Jun* 28*	*Jul 28*	*Aug 14*	*Herbicide (l/ha)*	*Sep* 27*	*Nov 17*
1	Diquat (18.7)	37	41	28	Diquat (18.7)	——	71
2	Diquat + Cutrine (18.7 + 18.7)	49	32	42	Diquat (18.7)	86	67
3	Aquathol K (56)	55	41	35	Diquat (18.7)	50	49
4	Aquathol K (56)	43	38	40	Endothol (56)	65	66
5	Diquat + Cutrine (18.7 + 18.7)	40	36	37	Endothol (56)	100	70

* Treatment dates.

percent cross-sectional coverage was greater in all plots than it was in summer and, generally, no reduction in coverage resulted from the fall treatments.

The general lack of success with herbicides that have been effective elsewhere is puzzling. Because of the control obtained in shallow areas but not in deeper areas, we think that application technique may account for some of the problem. Airboat and hand-gun applications were basically surface applied. The dense surface coverage of hydrilla, especially during fall, may have trapped herbicides near the surface, resulting in incomplete diffusion throughout the water column. This situation would account for success in shallow but not deeper areas. To remedy this problem, 4-ft-long hoses will be used in the future to inject the herbicide below the surface.

Some failures, especially in Lake Anne, may have been due to small plot sizes. The chemicals may have been diluted by the surrounding water before they were absorbed by hydrilla.

The general failure of all fall treatments may be due to physiological insusceptibility of hydrilla. However, hydrilla grew actively in Lake Wheeler where biomass increased considerably during August (G. J. Davis, personal communication). Also, tuber formation was not completed by September (G. J. Davis, personal communication) and physiological activity would be required to produce tubers which should enable the herbicide to work. Thus, application technique still appears to be the best explanation for the general lack of success with chemical treatments. The extremely dense hydrilla coverage that had developed by fall would have been difficult for surface-applied chemicals to penetrate. Therefore, only the tops of the plants were affected and regrowth was rapid.

Drawdown treatment

Historical records indicate that September through November is the driest period of the year in North Carolina. However, precipitation during that period in 1982 was 12 cm above average and the hydrosoil was never thoroughly desiccated.

Even with the exceptional amount of rainfall, a slight drop in moisure content was observed in the hydrosoil (Table 5). Decreases in tuber sprouting were observed in November, but all tubers incubated from the December and January samples sprouted.

The hydrophilic clays in the hydrosoil account for the persistent high moisture content of the sediments (Table 5). Most impoundments in the Piedmont area have a clay substitute underlying an accumulated organic, detrital layer. Many of the tubers are formed in this clay layer and will not be desiccated by a drawdown of a few months.

Table 5

Percent Moisture Content and Tuber Germination from Sediment Core Taken in Lake Anne Following Fall Drawdown

Depth Core cm	*Percent Moisture**	*SE***	*Percent Tuber Germination*
	15 Nov 1982		
0- 4	74.7	2.7	—
4- 8	66.2	2.1	—
8-12	46.8	10.4	—
12-16	21.9	1.7	—
	27 Nov 1982		
0- 4	68.4	1.6	88
4- 8	61.9	2.9	86
8-12	61.3	1.6	60
12-16	44.3	6.2	59
	27 Dec 1982		
0- 4	66.0	0.4	100
4- 8	60.8	0.9	100
8-12	47.0	1.5	100
12-16	31.4	3.1	100
	25 Jan 1983		
0- 4	52.5	2.2	100
4- 8	55.3	2.9	100
8-12	53.4	4.7	100
12-16	34.7	4.7	100

* Moisture was determined from three replicate samples.

** Standard error of mean.

ACKNOWLEDGEMENTS

Financial support for the research was provided by the University of North Carolina Water Resources Research Institute and the city of Raleigh, N.C. Financial support for control work was provided by the U.S. Army Engineer District, Wilmington; Wilmington, N.C., and matched by the North Carolina Office of Water Resources, Raleigh, N.C.

REFERENCES

Bowes, G., et al. 1977. "Adaptations to Low Light Levels by Hydrilla," *Journal of Aquatic Plant Management*, Vol 15, pp 32-35.

Fitzpatrick, L. A., et al. 1981. "Factors Influencing the Effectiveness of *Tilapia zilli* in Controlling Aquatic Weeds," Arizona Cooperative Fishery Research Unit, Number 81-1.

Haller, W.T. 1979. "Aquatic Weeds in Florida," *Proceedings of the Grass Carp Conference*. Shireman, J. V., ed., Institute of Food and Agricultural Sciences, University of Florida, Gainesville, pp 1-19.

Haller, W. T., and Sutton, D. L. 1975. "Community Structure and Competition Between Hydrilla and Vallisnera," *Hyacinth Control Journal*, Vol 13, pp 48-50.

Langeland, K. A., and Sutton, D. L. 1980. "Regrowth of Hydrilla From Axillary Buds," *Journal of Aquatic Plant Management*, Vol 18, pp 27-29.

Legner, E. F. 1978. "Effort to Control *Hydrilla verticillata* (Royle) With Herbivores *Tilapia zilli* (Gervais) in Imperial County Irrigation Canals," *Proceedings and Papers of the 46th Conference of the California Mosquito and Vector Association, Inc.* USA, pp 103-104.

Maceina, M. J., and Shireman, J. V. 1980. "The Use of Recording Fathometer for Determination of Distribution and Biomass of Hydrilla," *Journal of Aquatic Plant Management*, Vol 18, pp 34-39.

Miley II, W. W., Leslie, A. J., Jr., and Van Dyke, J. M. 1979. "The Effects of Grass Carp (*Ctenopharyngodon idella* Val.) in Vegetation and Water Quality in Three Central Florida Lakes," Bureau of Aquatic Plant Research and Control, Florida Department of Natural Resources, Tallahassee, Fla.

Rhodes, N. 1982. "Status of Hydrilla in North Carolina," *Proceedings of a Workshop on Hydrilla Management in North Carolina*, Witzig, A., Heimerman, J., and Partington, B., eds., UNC Water Resources Research Institute, Raleigh, N.C.

Sutton, D. L. 1977. "Grass Carp (*Ctenopharyngodon idella* Val.) in North America," *Aquatic Botany*, Vol 3, pp 157-164.

Terrell, J. W., and Terrell, T. T. 1975. "Macrophyte Control and Food Habits of the Grass Carp in Georgia Ponds," *Verh. Internat. Verein. Limnol;* Vol 19, pp 2515-2520.

Van, T. K., Haller, W. T., and Bowes, G. 1976. "Comparison of the Photosynthetic Characteristics of Three Submerged Aquatic Plants," *Plant Physiology*, Vol 58, pp 761-768.

Van, T. K., et al. 1977. "Effects of Light Quality on Growth and Chlorophyll Composition in Hydrilla," *Journal of Aquatic Plant Management*, Vol 15, pp 29-31.

AD-P003 615

THE "CAROLINA" SESSION

Status of Alligatorweed Control in North Carolina

by

K. A. Langeland,* C. A. Nalepa,** and K. G. Wilson**

INTRODUCTION

Alligatorweed (*Alternanthera philoxeroides*), a native to South America, was first identified in the United States in the 1890s. It was quickly recognized as a major aquatic weed problem. The plant's prolific growth habit, and rapid reproduction and dispersal cause severe detrimental impacts to water resources. Alligatorweed impedes navigation, causes flooding, and increases sedimentation of drainage and irrigation canals; it can also invade croplands. Surveys showed that by the 1960s over 160,000 acres of water in the southeastern United States was infested with the weed which ranged from Florida to Virginia (Gangsted 1977).

Alligatorweed continues to be a serious weed problem and infestations are increasing. A 1963 survey reported 376 acres of North Carolina waterways infested with alligatorweed (U.S. Army Corps of Engineers 1965); however, a recent survey has not been conducted. Heavy and widespread infestations were observed in the summer of 1983 that extended between North Carolina's northern and southern borders in the east and as far west as Johnston and Sampson Counties. It is apparent that alligatorweed infestations pose an increasing threat to navigation, recreation, and agriculture in North Carolina. Development of cost-effective herbicide recommendations and biological control procedures for alligatorweed is, therefore, imperative.

This report reviews the attempts to establish biological control suppressants of alligatorweed in North Carolina and presents preliminary findings of a cooperative effort between North Carolina State University (NCSU) and the North Carolina Department of Agriculture (NCDA) to develop an integrated alligatorweed management program in North Carolina.

BIOLOGICAL CONTROL EFFORT

During the period 1960-1962, G. B. Vogt of the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) explored South America for natural enemies of alligatorweed and succeeded in finding three insects that appeared to have potential for the suppression of this weed. Following long-term host-specificity studies, these insects were released and became established in areas of the southeastern United States:

a. *Agasicles hygrophila* Selman & Vogt (Coleoptera:Chrysomelidae) — alligatorweed flea beetle. Both larvae and adults feed on foliage of alligatorweed (Maddox 1968). First released in the United States in 1964 (Hawkes, Andres, and Anderson 1967).

* North Carolina State University, Raleigh, North Carolina.

** North Carolina Department of Agriculture, Raleigh, North Carolina.

b. Vogtia malloi Pastrana (Lepidoptera:Pyralidae:Phycitinae) — alligatorweed stem borer. Larvae feed on the internal wall and nodal septum of the hollow stem; damage is by girdling of the vascular tissues. First released in the United States in 1971 (Brown and Spencer 1973).

c. Amynothrips andersoni O'Neill (Thysanoptera:Phlaeothripidae) — alligatorweed thrips. Feeds on terminal growth of alligatorweed; damage is by stunting, wrinkling, and rolling leaves (Vogt, personal communication to O'Neill 1968). First released in the United States in 1967 (Coulson 1977).

The USDA, together with the Army Corps of Engineers, initiated a program for the release of these insects in North Carolina beginning in 1967. Table 1 is a current summary of all releases in North Carolina, compiled from Federal reports and NCDA records. The majority of the releases were of *A. hygrophila* (N >26,870 insects), but attempts were also made to establish the stem borer, *V. malloi*, at two sites in New Hanover County. Additionally, there was one possible release of *A. andersoni* in North Carolina; shipping permits were issued for their importation into North Carolina, but there are no records of their actual release.

Table 1
Releases of Biological Suppressants of Alligatorweed in North Carolina, 1967-1983*

County	*Site*	*Date*	*No. Agasicles Released*	*Date*	*No. Vogtia Released*
Columbus	Chadborn	1967	200		
	Lake Waccamaw	1967	400		
		1979	970		
Hertford	Catherine Creek	1969	1500		
New Hanover	USS-NC	1967	200		
		1967	300		
	Timme Pond**	1967	200		
		1967	500		
		1968	1200		
		1968	200		
	Greenfield Lake	1968	400	1971	4-ft² mat
		1970	1700	1972	unknown number of pupae
		1971	3500	1974	100+
		1971	"few"		
		1972	3500		
		1972	3000		
		1974	1000+		
	Oakly Plantation	1977	150	1971	100
		1979	1950	1972	100
		1979	20 egg masses	1977	100
	Catfish Lake	1982	200		
Pender	Willard	1983	600		
Sampson	Salemburg	1983	900		
Tyrrell	White's Canal	1968	400		
Washington	Canoby Creek	1968	400		
	Scuppernong River	1983	3500		
	TOTAL		27,800+		400+

* Compiled from Federal reports and NCDA records. This table is an update of information contained in a report by NCDA Biological Control Laboratory (1983), and is available from Plant Industry Division, North Carolina Department of Agriculture, PO Box 27647, Raleigh, NC 27611.

** Site destroyed in 1981.

Except for one population in Wilmington that lasted 1 year, releases of *Agasicles* in North Carolina have been unsuccessful. The three 1983 releases have not yet been checked to see if they survived the winter, but their establishment is unlikely. Inability to overwinter in North Carolina is probably due to a general lack of cold hardiness of this beetle; *Agasicles* does not undergo a winter diapause (Coulson 1977). The Charleston, S.C., area is the northernmost point on the east coast currently supporting a population of *Agasicles* (G. Buckingham, personal communication). Nevertheless, it is still possible that *Agasicles* can be used in an alligatorweed control program in North Carolina. First, yearly releases of the insect early in the growth season may prove effective. Second, there is evidence that an integrated approach to the control of alligatorweed (both herbicides and *Agasicles*) can be successful (Blackburn and Durden 1975). Third, it may be possible to select for a strain of *Agasicles* sufficiently cold-hardy to become established in North Carolina; this idea is currently being tested by the NCDA.

In 1983, the NCDA began culturing alligatorweed flea beetles (*Agasicles hygrophila*) for two purposes: the BioControl Laboratory plans some early season (1984) releases of the insect in Duplin County; and the laboratory is attempting to select for a strain of *Agasicles* that is sufficiently cold-hardy to withstand North Carolina winters. The *Agasicles* beetles were collected for culture from the northernmost point on the east coast where they are known to overwinter (Charleston, S.C., area).

In June of 1983, the Army Corps of Engineers released 3500 alligatorweed flea beetles in the Scuppernong River (seven sites) in Washington County. The NCDA surveyed these sites three times after the releases to determine if (a) the insects were surviving, and (b) they were exerting any control of the weed. In three of the sites, the beetles significantly increased in numbers and were damaging the alligatorweed mat on which they were released (Table 2). The NCDA plans to revisit these three sites early in 1984 to determine if any of the insects overwintered.

Despite the small numbers of *V. malloi* released (Table 1), this stem-boring moth is currently widespread along the coast of North Carolina. The distribution of *Vogtia* within this range, however, does not appear to be uniform, possibly due to site-to-site variation in the quality of alligatorweed (Maddox 1968). The hot, dry summer of 1983 favored *Vogtia* (P. C. Quimby, personal communication), and many alligatorweed mats destroyed by the stem borer were observed in eastern North Carolina (Table 2).

Amynothrips andersoni has not been found in this state; a program of releases is currently in the planning stages.

CHEMICAL CONTROL EFFORTS

Glyphosate is the current recommendation for alligatorweed control in North Carolina; however, a single treatment offers only temporary control and repeated treatments are expensive. Currently labeled aquatic herbicides, timing of application, application techniques, and experimental compounds are currently being evaluated for alligatorweed control in North Carolina.

Table 2
Results of NCDA Visits to *Agasicles* Release Sites*

Site	*3 August 1983*	*9 September 1983*	*26 October 1983*
Site 1	Eggs, larvae, adults of *Agasicles* present in immediate area of release, feeding signs present. *Vogtia* present and significantly damaging some mats.	Eggs, larvae, adults of *Agasicles* present. Scattered light damage around edges of mat. *Agasicles* present approx. 80 m from release site. *Vogtia* present, mats that appeared damaged 3 August now are flattened or under water. *Herpetogramma* present.	Eggs, larvae, adults of *Agasicles* present. Damage obvious approx. 110 m from release site. Significant damage limited to edges of mats — no mats completely destroyed. No *Vogtia* collected. *Vogtia* damaged mats completely submerged; other weeds have moved in. *Herpetogramma* not present.
Site 2	Eggs, larvae, adults of *Agasicles* present at site of release. Extensive defoliation at release point. Little no *Vogtia* damage.	Eggs, larvae, adults of *Agasicles* present. Significant damage approx. 150 m from release point. Regrowth of alligatorweed in area of release. Some *Vogtia* damage present.	
Site 3		Unable to find release site 3.	
Site 4	Site inaccessible to close inspection. Larval *Agasicles* present. Feeding damage light (< 5%). No Vogtia damage observed.	No *Agasicles* recovered. *Vogtia* present and lightly damaging mats.	
Site 5	No *Agasicles* recovered. Feeding damage very light (< 2%). No *Vogtia* damage observed.	No *Agasicles* recovered. Several spots heavily damaged by *Vogtia* (> 80%).	
Site 6	Larval and adult *Agasicles* present. Damage present (< 20%), but localized to immediate area of release. *Vogtia* present and significantly damaging some mats.	No obvious *Agasicles* damage. Site of *Agasicles* release shows extensive *Vogtia* damage middle of mat completely flattened, just a fringe of healthy alligatorweed around edge.	*Agasicles* damage rare. *Vogtia* damaged areas of mat sank.
Site 7	Site inaccessible to close inspection. Light damage by *Vogtia* appears present.	*Agasicles* damage around edges of mat. Egg masses and larvae present. No obvious *Vogtia* damage.	[illegible]

* Insects released 22 June 1983, Washington County, North Carolina.

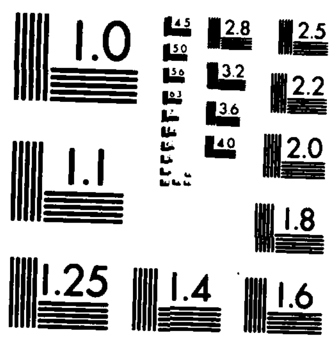
AD-A142 827 PROCEEDINGS OF THE ANNUAL MEETING AQUATIC PLANT CONTROL RESEARCH PROGRAM (..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR.. JUN 84 3/3

UNCLASSIFIED WES/MP/A-84-4 F/G 6/6 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Alligatorweed control was initially excellent and consistent for all applications with Rodeo® and Rodeo + Sonar® (Table 3). Regrowth from axillary buds, however, began 2 weeks after application of Rodeo, remained vigorous, and increased throughout the 9-week period of observation. Temporary control with Rodeo is consistent with label recommendations which refer to "partial" control of alligatorweed. The large number of axillary buds, which produce glyphosate-symptom-free growth, is surprising considering the extensive translocation of glyphosate that occurs in other species (Sprankle, Meggitt, and Penner 1975; Claus and Behrens 1976). Glyphosate is apparently not translocated to the quiescent buds and/or is metabolized at or before it reaches the axillary buds.

When Sonar was tank-mixed with Rodeo, the response was similar as to Rodeo alone. However, regrowth was somewhat delayed because axillary buds that initiated early aborted shortly after initiation. Buds which aborted were chlorotic, typical of fluridone symptomology. After 6 weeks in the Perquimans County test, and 9 weeks in one of the Washington County applications, vigorous growth was produced from axillary buds.

Table 3

Effectiveness of Several Herbicide Treatments for Control of Alligatorweed in North Carolina

Herbicide	*Rate/acre**	*Level of Control** at Weeks After Treatment* 2	4	6	9	*Location (County)*	*Site Description*
Rodeo	0.75 gal	—	99	80	—	Perquimans†	Damp soil
Rodeo	0.75 gal	—	99	95	—	Perquimans	Damp soil
Rodeo	0.75 gal	—	98	90	—	Perquimans	Damp soil
Rodeo	0.75 gal	98	—	—	40	Washington††	Damp soil
Rodeo	0.38 gal	90	—	—	40	Washington	Saturated soil
Sonar 4AS	0.50 gal	—	0	50	—	Perquimans	Damp soil
Sonar 4AS	0.50 gal	—	50	50	—	Perquimans	Damp soil
Sonar 4AS	0.50 gal	—	0	50	—	Perquimans	Damp soil
Sonar 4AS	0.50 gal	50	—	—	90	Washington	Saturated soil
Sonar 5P	20 lb	0	—	—	0	Washington	Slow moving water, ca. 4-in. depth
Rodeo + Sonar	0.75 gal + 0.50 gal	—	99	98	—	Perquimans	Damp soil
Rodeo + Sonar	0.75 gal + 0.50 gal	—	100	99	—	Perquimans	Damp soil
Rodeo + Sonar	0.75 gal + 0.50 gal	—	100	98	—	Perquimans	Damp soil
Rodeo + Sonar	0.75 gal + 0.50 gal	60	—	—	95	Washington	Saturated soil
Rodeo + Sonar	0.38 gal + 0.25 gal	40	—	—	100	Washington	Standing water, ≤1 in. deep
Karmex	40 lb	0	—	—	100	Washington	Damp soil
AC 252,925	0.25 gal	—	0	100	—	Perquimans	Damp soil
AC 252,925	0.25 gal	0	—	—	100	Perquimans	Damp soil
AC 252,925	0.17 gal	0	—	—	100	Washington	Standing water, ≤1-in. deep

* All applications with a handgun in 100 gal of water containing 1.0% Polycontrol. Rodeo, and Rodeo + Sonar. Applications contained 0.5% X-77 surfactant.

** 0 = no control, 100 = complete control.

† Application date, 8/11/83.

†† Application date, 9/8/83.

Alligatorweed responded inconsistently to Sonar. In Perquimans County tests, where there was no water standing in the ditch and alligatorweed was growing in damp soil, no greater than 50-percent control was observed. Six weeks after treatment, all older leaves had abscised, stems were inconsistently chlorotic, and many initiating buds were chlorotic and aborting. Vigorously growing axillary buds without symptoms were beginning to appear. Control appears to be related to the amount of water in the root/rhizome/stolon zone because much better control was observed with Sonar in saturated soil compared to damp soil, and where there was shallow standing water complete control was observed with Rodeo + Sonar. Root absorption of fluridone may, therefore, be facilitated by water.

Sonar 5P applied to slow-moving water in a 30-ft-wide by 4-ft-deep drainage canal did not control alligatorweed. Symptoms, described above, were observed 2 weeks after treatment but no reduction in cover occurred. Symptons were observed 5 miles upstream and downstream from the treated area, indicating that fluridone moved away from the treated area.

Control of alligatorweed with Karmex® was slow but complete. Nine weeks after treatment all aboveground alligatorweed was moribund. Rhizomes appeared to have viable axillary buds; however, these were not initiating and would hopefully not survive after emergence.

The herbicide AC 252,925 (American Cyanamid) gave the most effective control of alligatorweed. Two weeks after treatment apical growth turned white and aborted. Four weeks after application this symptom was observed on axillary growth. Complete control was observed 6 weeks after application and regrowth was not observed during 1983.

REFERENCES

Blackburn, R. D., and Durden, W. C. 1975. "Integrated Control of Alligatorweed," Aquatic Plant Control Program, Technical Report 10, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Brown, J. L., and Spencer, N. R. 1973. "*Vogtia malloi*, A Newly Introduced Phycitine Moth (Lepidoptera: Pyralidae) to Control Alligatorweed," *Enviro. Ent.*, Vol 2, No. 4, pp 519-523.

Claus, J. J., and Behrens, R. 1976. "Glyphosate Translocation and Quackgrass Budkill," *Weed Science*, Vol 24, pp 149-176.

Coulson, J. R. 1977. "Biological Control of Alligatorweed 1959-1972, A Review and Evaluation," U.S. Department of Agriculture Technical Bulletin No. 1547, Washington, D.C.

Gangsted, E. O. 1977. "Biological Control of Alligatorweed, 1959-1972," Agricultural Research Service, U.S. Department of Agriculture, and U.S. Army Corps of Engineers, Washington, D.C.

Hawkes, R. B., Andres, L. A., and Anderson, W. H. 1967. "Release and Progress of an Introduced Flea Beetle, *Agasicles* N. sp., to Control Alligatorweed," *Journal, Econ. Ent.* Vol 60, pp 1476-1477.

Maddox, D. M. 1968. "Bionomics of an Alligatorweed Flea Beetle *Agasicles* sp. in Argentina," *Ann. Ent. Soc. Amer.*, Vol 61, No. 5, pp 1299-1305.

North Carolina Department of Agriculture, Biological Control Laboratory. 1983. "Biological Control of Alligatorweed with Insects: Current Status in North Carolina," Vol III, No. 1. Raleigh, N.C.

Sprankle, P., Meggitt, W. F., and Penner, D. 1975. "Absorption, Action, and Translocation of Glyphosate," *Weed Science*, Vol 23, pp 235-240.

U.S. Army Corps of Engineers. 1965. "Expanded Project for Aquatic Plant Control," 89th Congress, 1st Session, House Document No. 81.

THE "CAROLINA" SESSION

A Major Utilities Program to Manage Aquatic Weeds

by
David H. Schiller*

INTRODUCTION

Carolina Power & Light Company (CP&L) is an investor-owned electric utility serving over 800,000 customers in eastern and western North Carolina and northeastern South Carolina. Total system generating capacity is 8,740 MW, with approximately 70 percent from coal, 25 percent from nuclear fuel, and 5 percent from oil and hydro sources. CP&L is currently about the 15th largest electric utility in the United States, based on total electric sales and value of equipment in 1983.

Aquatic weeds affect CP&L in three ways. One is the direct impact to the recreational uses of our lakes and reservoirs. The Company is committed to the public use of the lands and impounded waters associated with its various power plants to the extent practical and consistent with the operation of the plants. Consequently, most of our lakes are heavily utilized by the public for fishing, swimming, boating, and other types of aquatic recreation. Heavy growths of aquatic weeds restrict these activities, thereby reducing the public's enjoyment.

Another effect of aquatic weeds is the degradation of water quality when large quantities of weeds die and release nutrients into the water, causing algae blooms. This has occurred several times in recent years and has contributed to fish kills.

However, the most significant effect of aquatic weeds on CP&L is the blockage of water intake structures at the power plants. Electric generating plants utilize large quantities of cooling water in the process of power production. When aquatic weeds are carried into the intake structure and block or reduce water flow, electric generation must be reduced and, in severe cases, the plant may be shut down. This can result in substantial financial losses to the Company and possible interruptions in electrical service to our customers, should the event occur when peak demand is utilizing all available reserve generating capacity.

HISTORY OF CP&L's PROBLEMS

CP&L first experienced problems with aquatic weeds in 1974 at its L. V. Sutton Steam Electric Plant near Wilmington, N.C. Bladderwort (*Utricularia vulgaris*) invaded the shallow (6 ft deep) 1,100-acre cooling lake, and late each summer large quantities broke loose and were carried into the intake structure. Eventually in 1979, the screens in front of the intake pumps were sufficiently blocked so that the power plant had to be temporarily shut down. In the spring of 1980 and each year

* Carolina Power & Light Company, Raleigh, North Carolina.

since, *Tilapia zilli* have been stocked at a density of about 50 fish per acre and bladderwort declined to near zero levels. Impingement of bladderwort has not been a problem since then.

However, the elimination of bladderwort apparently made the habitat available to other plant species. In 1982 and 1983 large stands of southern naiad (*Najas guadalupensis*), pondweed (*Potamogeton pusillus*), and coontail (*Ceratophyllum demersum*) grew profusely throughout the lake and contributed to recreational impacts, a blue-green algae bloom, and impingement problems at the power plant's intake structure.

At Hyco Reservoir, *Egeria densa* was first observed by Company biologists in the early 1970s. This 4,350-acre reservoir provides both cooling and makeup water for CP&L's Roxboro Steam Electric Plant. At present, the infestation is mostly confined to a 500-acre area in the northwest corner of the reservoir. However, several other spot infestations have been observed throughout the reservoir, indicating that it is spreading. Although no operational problems have occurred because of the egeria, its presence and apparent spread indicates that it may cause power plant operational problems in the future. Egeria has already impacted recreational uses (swimming, boating, and fishing) of the reservoir in the areas where it occurs.

In 1983, *Hydrilla verticillata* was discovered growing in two locations in Hyco Reservoir. Both of these locations are near the only public boat ramp on the reservoir, indicating that hydrilla was probably introduced as fragments on boats from a nearby infested water body. Total areal coverage of hydrilla is small (less than 0.25 acre), but its presence represents potential operational and recreational impacts.

CP&L'S AQUATIC PLANT MANAGEMENT PROGRAM

CP&L's present aquatic plant management program is divided into four general areas. These are education, research, monitoring, and control. These activities are designed to prevent the introduction of nuisance aquatic weeds into the Company's reservoirs, to determine the best method of dealing with them if they occur, and to carry out activities to control them when it has been determined necessary.

Education

The Company has placed aquatic weed information signs at all public boat ramps on the Company's system. These signs are similar to those utilized by the Tennessee Valley Authority and inform the public about the problems associated with aquatic weed introductions. They ask each boater to inspect his/her boat and trailer for weed fragments and to report any weed problems that have been observed. An in-house procedure has been established to direct those reports to the appropriate biologist.

In August 1983, a brochure giving information about hydrilla was mailed with each customer's monthly electric bill. Over 800,000 of these "bill-stuffers" were sent out as part of a cooperative program with the North Carolina Department of Natural Resources and Community Development. It is the intent of these activities

to educate the public that nuisance aquatic weeds will detract from the recreational values of the reservoirs and possibly cause electrical interruptions if power plant operations are sufficiently affected.

Research

Research activities have been carried out over the past two summers. In 1982, Company biologists conducted a detailed program to evaluate three methods to control *Egeria densa* in Hyco Reservoir. Methods evaluated were chemical (diquat, Aquathol K, and Cutrine Plus in various combinations), biological (tilapia), and mechanical (harvesting). It was concluded that diquat applied at 2 gal/acre was most effective for localized control such as around boat docks, swimming areas, and other high-use areas and that tilapia stocked at a density of 300 fish per acre could significantly reduce the overall standing crop of weeds.

During the last half of 1983, a 2-year program to compare the efficacy of grass carp and tilapia was initiated at the Company's L. V. Sutton Plant. This program was designed to provide information for controlling coontail, southern naiad, and pondweed. Data are still being collected, but preliminary results indicate that predation by largemouth bass may require stocking larger grass carp than originally stocked. Weed biomass in the control area did not differ significantly from that in the two treatments (herbivorous fish plots).

Plans for research in 1984 at the Sutton Plant include a continuation of the evaluation of grass carp efficacy, evaluations of a mechanical harvester by means of the Waterways Experiment Station HARVEST computer model, and field evaluations with Sonar, Aquathol K, and diquat. This study is being designed to provide information about selecting the best method of control as well as to provide a reduction in impingement of weeds at the Sutton Plant intake structure.

Monitoring

All impoundments in the CP&L system are systematically surveyed for potentially troublesome aquatic weeds. These surveys are carried out at intervals from one per year to one every month, depending on the predicted or actual severity of the problem. Outboard boats, airboats, and the Company's helicopter are utilized as the situation dictates. Aerial photography (both false-color infrared and color positive) is used to document observed conditions. These surveys are designed to detect new infestations of weeds or to monitor existing populations.

In addition to special surveys, aquatic weeds are often observed by Company biologists during the course of other environmental monitoring programs. An in-house awareness program is used to acquaint biologists in various phases of field work (fisheries, plankton, water chemistry, benthos, etc.) so that they are able to recognize potential problem species that are encountered during the course of their field sampling.

Control

At present, only one regular aquatic weed control program is being carried out. This is at Hyco Reservoir where *Egeria densa* is being treated. Based on the results of the field evaluations that took place in 1982, diquat is being applied at 2 gal/acre

with a polymer carrier. The Company has purchased an airboat and this work is being carried out in-house.

The goal of this program is to contain the weeds in the area where they occur, not to eliminate them from the reservoir. This is being done by treating localized high-use areas within the general infestation so as to reduce the incidence of fragmentation. Hopefully, this will reduce the impact to the recreational public and also the chance of egeria spreading to other areas of the reservoir. In addition, localized spot infestations in other locations in the reservoir are being treated with the hope of eliminating them.

Because hydrilla was discovered only recently, a regular systematic control program has not been developed. The present infestation consists of about 15 patches, most less than 10 ft in diameter. During September and October 1984 granular Sonar was applied over the general area of infestation at 40 lb/acre. Follow-up treatments consisted of applying handfuls of Sonar directly on each patch of hydrilla. Chlorosis (typical sympton of Sonar) was observed in all treated areas, but the final results will not be known until mid-1984. Present plans are to continue to treat this species with Sonar and to initiate intensive surveys to locate any undetected infestations. Hopefully, the infestation was discovered early enough that by actively attacking it, hydrilla can be eliminated from the reservoir.

SUMMARY

Carolina Power & Light Company has recently experienced aquatic weed problems in two of its impoundments. These problems have impacted power plant operations, water quality, and recreational activities. The Company is actively pursuing a program to deal with these weed problems through education, research, monitoring, and control activities.

THE "CAROLINA" SESSION

Aquatic Macrophyte Distribution in the Santee Cooper Lakes

— A Study Approach —

by
Richard Harvey*

BACKGROUND

About 2-1/2 years ago the Union Camp Corporation announced its intention to construct a pulp and paper mill on the Wateree River approximately 20 miles upstream of Lake Marion. Concerns were immediately raised by various groups regarding a number of potential adverse environmental impacts from the proposed facility. Those who use the system downstream of the intended wastewater discharge location were primarily concerned about the mill's impact on fishing and on an existing aquatic macrophyte problem in upper Lake Marion. Even more specifically, most users and many agencies were concerned about a potential toxic impact of the mill's effluent on the early life stages of striped bass, which spawn in the Wateree and Congaree Rivers. These same groups were also concerned about the impact of the additional nutrient load from the facility on the macrophyte problem.

Because of these concerns, a local group, the Citizens to Preserve the Santee-Cooper (The Citizens), headquartered in Sumter decided to oppose the construction of the facility and filed a law suit requesting that an Environmental Impact Statement (EIS) be prepared. It was hoped that studies required through the EIS process would address the concerns expressed by their members and other interested groups and agencies prior to a final decision being made.

In response to this request it was the contention of the Department of Health and Environmental Control (DHEC) that compliance with new source performance requirements of the NPDES permit regulations by the mill would maintain air and water quality standards. This contention was based upon mathematical modeling results supplemented by additional knowledge about the system obtained through their various monitoring programs.

Because of DHEC's position and the relatively limited funds available to the Sumter group, a settlement agreement was reached between the Citizens, Union Camp, and DHEC. The agreement called for Union Camp to donate $150,000 to the Citizens to help offset some of the expenses associated with their law suit. It also called for Union Camp to donate $1,000,000 to DHEC for use in conducting special water quality studies in the Santee-Cooper River Basin over a 10-year period.

Since the Union Camp Corporation was required to conduct special water quality studies by its NPDES permit, it was the intent of the agreement that the studies

* South Carolina Department of Health and Environmental Control, Columbia, South Carolina.

funded by the $1,000,000 donation not be structured so as to represent an after-the-fact environmental impact assessment of the facility approval. The only additional requirement intended or specifically stipulated by the agreement was that initial efforts of the study were to be concentrated on "the present causes of the apparent tendency of the Santee-Cooper lakes toward eutrophication and to develop means to prevent further deterioration of the lake system and if possible a reversal of the tendency of the lakes toward deterioration." The concerns which exist regarding the potential toxic impact of the effluent on striped bass eggs and prolarvae are being addressed by studies conducted by Union Camp under the guidance of the South Carolina Wildlife and Marine Resources Commission and the DHEC.

Due to the tremendous amount of controversy surrounding the entire process, DHEC decided to hire someone from outside the agency to manage the program. They also decided that to avoid charges of bias the studies should generally not involve their water quality monitoring staff. This meant that studies which could not be conducted by the project manager and his staff would have to be contracted out.

With these identified constraints I was hired as project manager for the basin-wide studies, beginning work the third week in January 1983. My first task was to become familiar with the Marion-Moultrie system, its water quality problems, and the requirements of the three-party agreement. During the course of these evaluations, it became readily apparent that the eutrophication problem everyone was concerned about was the weed problem. It also became apparent that no specific studies were being conducted to quantify the weed problem or, with one exception, to understand what specific factors control the growth and distribution of the weeds throughout the system. The one exception was a nutrient loading/trophic status study being conducted by John Inabinet of the Santee-Cooper PSA.

Cont'd

STUDY APPROACH

Mapping

The basic study approach selected for the initial phases of the project was to concentrate on problem identification and assessment. In order to identify and assess the macrophyte situation in Upper Lake Marion, above I-95 where the majority of the weeds exist, it was decided that mapping the weed distribution for several successive years would be appropriate. Weed distribution maps for these years could then be compared to information available on the weed distributions from previous years. Comparisons of this type could then be used to identify trends in species compositions and distributions and determine the rate of encroachment of the weeds into the lake. Comparisons could also be made with additional data being developed as part of the study on the environmental conditions (depth, substrate composition, etc.) which exist in the macrophyte-infested areas. These comparisons will be used in an effort to identify relationships which may exist between weed growth and distribution and environmental conditions which exist throughout the Marion-Moultrie system. It is hoped that if such relationships can be established, then reasonable projections of where the weeds might become a problem in the future can be made.

Macrophyte distribution data for this past season was obtained for Lake Marion above I-95 using two different techniques. The most time-consuming and accurate procedure involved mapping the weeds using an airboat along with a Motorola Mini-Ranger III Automatic Positioning System (APS) supplied and operated by the U.S. Geological Survey (USGS). Basically, the procedure involved locating the perimeter of specific weed beds by using a recording fathometer, a de-thatching rake, or by diving; delineating that perimeter with buoys; and driving the airboat around the buoys while the APS logged the boundary coordinates. Biomass samples from each weed bed were obtained by University of South Carolina (USC) students for weighing and identification.

The mapping procedure took approximately 2 months to complete. Prior knowledge regarding planned herbicide spraying in the area allowed mapping of about 95 percent of the area before the spraying occurred. Mylar overlays of each mapped area have been produced by USC using the APS coordinate and biomass samples data. Macrophyte distribution data for this past season were also obtained from false-color infared photographs taken of the system on 8 September through a cooperative agreement with the U.S. Environmental Protection Agency's Environmental Photographic Interpretation Center (EPIC). These photographs were taken in order to assess the applicability of using aerial photography to evaluate historic and future macrophyte distributions. Unfortunately, the photographs taken this past September were made after most of the weed spraying had already occurred. However, comparisons of these photographs to weed beds still in existence after the spraying indicate that aerial photographs should be useful in a qualitative identification of historic and future weed distributions.

Our weed mapping results for the 1983 growing season revealed that, excluding the swamp system, there were approximately 3300 acres of weeds in the "open water" areas of upper Lake Marion. This included about 1800 acres of egeria, 1000 acres of primrose, and 150 acres of hydrilla. To keep these numbers in perspective, it should be noted that the total area (swamp and water) of upper Lake Marion is approximately 40,000 acres, with the swamp system comprising about half of that area.

Environmental parameters

Literature reviews and interviews with weed "experts" conducted to date predominately indicate that, with respect to weed growth, critical environmental parameters to be concerned with are depth, light penetration (Haller 1982; Spence and Chrystal 1970; Sculthorpe 1967), substrate composition (Barko and Smart 1980, 1981; Martin, Bradford, and Kennedy, no date), interspecific competition (Misra 1938; Hestand and Carter 1977), and the physical stability (sheltered areas, wave action, etc.) of an area (Jupp and Spence 1977). Surprisingly, with the problem species of weeds which presently exist within the system, i.e. *egeria, hydrilla*, etc., nutrient loadings and concentration distributions are not identified as critical. The consensus is that rooted macrophytes are capable of satisfying their nutrient requirements from substrate nutrient sources (Best and Mantai 1978; Barko and Smart 1980, 1981; Denny 1972; Haller, personal communication) and that nutrient availability rarely, if ever, limits macrophyte growth and distribution (Martin,

Bradford, and Kennedy, no date). This also implies that creating a situation where nutrients could be limiting would be extremely difficult at best and probably impossible from a practical standpoint (Haller, personal communication). However, in spite of this consensus, a nutrient loading/distribution study is being conducted in cooperation with the PSA to ensure that this nutrient/macrophyte relationship also exists in the Santee-Cooper Lakes and to evaluate nutrient/phytoplankton relationships in the system.

In order to investigate the identified critical parameters, a number of special studies are being conducted in cooperation with the USGS office in Columbia and with the Waterways Experiment Station (WES) Aquatic Plant Control Research Program.

When discussing Lake Marion's weed problem with those who have experience with similar situations, no one is surprised to find out that the macrophytes are predominately found in the upper reaches of the system. They state that macrophyte distributions in reservoirs are generally directly associated with areas that are subjected to high sediment loading and infilling. In order to investigate if such a relationship exists in Lake Marion, sediment loading studies are being conducted by the USGS along with bathymetric profile mapping.

Based upon data collected in the late 1960s, the USGS estimated that upper Lake Marion receives approximately one million tons of sediment each year. Long-time lake users familiar with upper Lake Marion report that numerous areas once accessable are now inaccessable because of sediment infilling. In order to determine if the sediment loading rate measured in the late 1960s has increased or decreased, automatic suspended solids sampling stations have been established on both the Congaree (at Highway 601) and Wateree (at the South Carolina Electric and Gas facility) Rivers. These sampling stations will be operated for a minimum of 2 years with samples initially obtained every 6 hr. Once correlations have been established (if possible) between suspended solids concentrations and stream flow, the sampling frequency may be reduced.

In order to determine where and how much of these solids are deposited, samples are also obtained in the Santee River below Lake Marion, in the Diversion Canal between Marion and Moultrie, and in the Tail Race Canal below Lake Moultrie. Upon completion of the Rediversion Project, samples will also be obtained from the Rediversion Canal. To specifically identify where within each lake the solids have been deposited, sediment cores have already been obtained and bathymetric profile mapping has been initiated by the USGS.

Sediment cores were obtained from 20 sites throughout the Marion-Moultrie system, including Sparkleberry Swamp. These cores are currently being analyzed using Lead-210 techniques to determine when specific layers were deposited. This information will be supplemented by comparing data on historic elevations to bathymetric contour profiles, which will be generated over the next year.

With regard to substrate composition and its influence on macrophyte distribution, specific studies to evaluate possible relationships in the system are presently being conducted by Dr. John Barko at WES. Dr. Barko's current research indicates that substrate composition may play an important role in determining macrophyte

distributions throughout a system (Barko 1984). For example, he has found that rooted macrophytes (*Hydrilla* and *Egeria*) do not appear to grow well in sediment that is greater than 75 percent sand or 15 percent total organic carbon (TOC). These findings may be relative to the weed distributions in Lake Marion and Lake Moultrie. Our surveys have indicated that extensive areas of the system with sand substrate are virtually free of *Hydrilla* and *Egeria*. These areas include most of the open waters in Lake Moultrie and many of the tributary arms of lower Lake Marion. In fact, our studies to date have identified nuisance macrophytes only in shallow (less than 10 ft), relatively sheltered areas, with either a clay or clay-sand substrate.

Other studies

In addition to these studies, which are specifically directed at understanding how environmental conditions throughout the system influence macrophyte distributions, a number of other studies are being conducted in the system. These additional studies are primarily designed to improve our understanding of the system's ability to assimilate point and nonpoint source loadings. The most extensive of these efforts is a series of dye studies presently being conducted in both lakes. Dye dumps have been or will be made during both high and low flow conditions throughout the system with samples obtained throughout each impacted segment. Evaluation of the data from these surveys will be used to determine circulation patterns and hydraulic retention times. Preliminary results obtained from two such surveys conducted on Lake Moultrie indicate that prevailing winds play a significant role in determining circulation patterns in that portion of the system. Observed hydraulic retention times were also found to be shorter than originally anticipated.

Studies such as these supplemented by algal growth potential investigations and surveys to determine chlorophyll, nutrient, and turbidity distributions will significantly improve our understanding of the system's ability to assimilate nutrients. Other studies ongoing or being considered include investigations of the relationship (if any) of macrophyte distributions and flow conditions in the Wateree and Congaree Rivers along with studies to evaluate the ecological impact of macrophyte control programs.

CONCLUSIONS

In conclusion, increasing our knowledge of the factors which influence the growth and distribution of macrophytes within the Santee-Cooper Lake System will not only facilitate our understanding of the existing distributions (primarily above I-95 and below Lake Moultrie in the Cooper River) but also allow us to make more responsible projections about where the weeds might become a problem in the future. This type of information, along with the additional assimilative capacity studies, should also result in a significantly improved ability by all concerned agencies to make sound water quality management decisions in the future.

REFERENCES

Best, M. D., and Mantai, K. E. 1978. "Growth of *Myriophyllum:* Sediment or Lake Water as the Source of Nitrogen and Phosphorus," *Ecology*, Vol 59, No. 5, pp 1075-1080.

Barko, J. W., and Smart, M. R. 1981. "Sediment-Based Nutrition of Submersed Macrophytes," *Aquatic Botany*, Vol 10, pp 339-352.

Barko, J. W., and Smart, M. R. 1980. "Mobilization of Sediment Phosphorus by Submersed Freshwater Macrophytes," *Freshwater Biology*, Vol 10, pp 229-238.

Barko, J. W. 1984. See pp 140-147 of this proceedings.

Denny, P. 1972. "Sites of Nutrient Absorption in Aquatic Macrophytes," *Journal of Ecology*, Vol 60, pp 819-829.

Jupp, B. P., and Spence, D. H. N. 1977. "Limitations of Macrophytes in a Eutrophic Lake, Lock Leven; II Wave Action, Sediments and Waterfowl Grazing," *Journal of Ecology*, Vol 65, pp 431-446.

Haller, W. T. 1982. "Hydrilla Identification, Environmental Habitat and Growth," *Proceedings of A Workshop on Hydrilla Management in North Carolina*. A. Witzig and J. Heimerman, eds., May 1982.

Hestand, R. S., and Carter, C. C. 1977. "Succession of Various Aquatic Plants After Treatment with Four Herbicides," *Journal of Aquatic Plant Management*, Vol 15, pp 60-64.

Martin, J. B., Bradford, B. N., and Kennedy, H. G. No Date. "Factors Affecting Growth of *Najas* in Pickwick Reservoir," *Publication of National Fertilizer Development Center*, Tennessee Valley Authority, Muscle Shoals, Ala.

Misra, R. D. 1938. "Edaptic Factors in the Distribution of Aquatic Plants in the English Lakes," *Journal of Ecology*, Vol 26, pp 411-451.

Sculthorpe, C. D. 1967. *The Biology of Aquatic Vascular Plants*, Edward Arnold Ltd., London.

Spence, D. H. N., and Chrystal, J. 1970. "Photosynthesis and Zonation of Freshwater Macrophytes: I. Depth Distribution and Shade Tolerance," *New Phytology*, Vol 69, pp 205-215.

THE "CAROLINA" SESSION

Aquatic Plant Problems and Management in South Carolina

by
Danny L. Johnson*

BACKGROUND

South Carolina has a number of public water bodies where aquatic plants create important water use problems. Most of these plant problem areas occur in the coastal plain which covers the eastern half of the state. The coastal plain is characterized by shallow, fertile waters and a long growing season, all of which create an ideal environment for aquatic plant growth. Additionally, most of South Carolina's problem plants are nonnative species, and the coastal area was probably the site of introduction for a number of these exotic species. Upstate waters can also have plant problem areas, but, currently, infestations in this region are less frequent and less severe. In addition to public waters, there are tens of thousands of private lakes and ponds in South Carolina and many of these private waters also have problem weed infestations.

INFESTED AREAS

Lake Marion

The most significant plant problem area in terms of area of coverage is Lake Marion, the larger of the two Santee-Cooper Lakes. Lake Marion is a 110,000-acre upper coastal plain reservoir constructed for hydroelectric power production. While the total extent of plant coverage is uncertain, approximately the upper fourth of the lake, including a headwater swamp, is heavily infested with weeds. Problem plant species include Brazilian elodea (*Egeria densa*), hydrilla (*Hydrilla verticillata*), slender naiad (*Najas minor*), pondweeds (*Potamogeton* spp.), waterprimrose (*Ludwigia uruguayensis*), and alligatorweed (*Alternanthera philoxeroides*). Alligatorweed became a problem soon after the lake was impounded in the 1940s, but was later largely displaced by waterprimrose. Brazilian elodea became established in the lake in the 1960s and has developed into the most abundant plant species at present. Hydrilla was found in Lake Marion in 1982 and currently occurs in scattered populations over a several thousand acre area. Based on the experience of other states with hydrilla and the presence of extensive shallow-water habitat in Lake Marion, it is feared that this plant will become the dominant nuisance weed and spread to previously uninfested areas of the lake.

Plant management efforts have occurred at various levels of intensity in Lake Marion ever since alligatorweed first became a problem. In recent years, control activities have been primarily directed toward Brazilian elodea and other submersed plants. There have been significant reductions in elodea infestations in

* South Carolina Water Resources Commission, Columbia, South Carolina.

areas where chemical controls have been applied; however, treatments usually must be repeated at 1- or 2-year intervals. Limited funding has prevented more intensive control efforts which are needed to further reduce nuisance weed growths at Santee-Cooper.

Back River Reservoir

Back River Reservoir is a 900-acre industrial water supply and recreational reservoir in the lower coastal plain. The city of Charleston also uses this reservoir for an auxiliary municipal water supply. Brazilian elodea occurs in about one half of the reservoir and has caused problems by clogging industrial water intakes and impeding recreation. The entire shoreline is heavily infested with waterprimrose and alligatorweed and, recently, waterhyacinth (*Eichhornia crassipes*) has invaded and is proliferating. Plant control operations have been conducted by one of the industrial water users, but this effort has been limited to the vicinity of the user's intake where screen clogging frequently occurs. More extensive control operations for elodea and waterhyacinth are needed at Back River Reservoir to prevent further use impairment.

Goose Creek Reservoir

Goose Creek Reservoir is a 600-acre recreational and auxiliary water supply reservoir located near Back River Reservoir. This impoundment has been heavily infested with waterhyacinth in recent years. These plants have hindered recreation and impeded water flow to the extent that flooding of residential property in the upstream watershed has increased. Major control efforts in 1982 and a maintenance program in 1983 have reduced hyacinth populations to a nonproblematic level. A continued management effort will probably be required to prevent redevelopment of the heavy infestation which occurred prior to 1982.

Cooper River

The Cooper River is a coastal stream which flows from Lake Moultrie (the smaller Santee-Cooper lake) to Charleston Harbor. During the 1700s, numerous impoundments were constructed adjacent to this river for the purpose of rice cultivation. These impoundments are no longer used for their intended purpose, but currently constitute an important part of the Cooper River ecosystem and are used extensively by fishermen and waterfowl hunters. Brazilian elodea infests nearly all of these impoundments (approximately 4000 acres) and greatly restricts recreational use. The impoundments are tidally influenced and, at low tide levels, the area is virtually nonnavigable. Due to insufficient funding, no control operations have been conducted on these impoundments.

Savannah River

The Savannah River bordering South Carolina and Georgia has problematic infestations of Brazilian elodea and other submersed plants in the middle and lower reaches. Recreation, hydroelectric power production, and water withdrawals are adversely affected by these plants. Problems associated with interstate water responsibilities, municipal water supplies, and lack of funding have prevented plant control operations.

Black Water streams

The Little Pee Dee River, Black Creek, and North Fork Edisto River are typical of coastal plain black water streams in South Carolina which are frequently infested with alligatorweed. In the past, these areas were managed with an integrated program of chemical and biological control. Most control efforts were reduced or discontinued in the mid-1970s and subsequently the plant populations have increased and are again becoming a concern. Reintroduction of biological control agents at a number of these streams is being planned for 1984.

Coastal counties

Several coastal counties in South Carolina are experiencing problems with the common reed (*Phragmites*). This plant is established in certain dredged material disposal areas and impoundments. The most troublesome infestations occur in State waterfowl management impoundments in Georgetown County. The South Carolina Wildlife and Marine Resources Department has had some success with chemical control of *Phragmites* in impoundments; however, more funding assistance is needed in this area.

Upstate water bodies

Lake Greenwood and Lake Bowen are two upstate water bodies with plant infestations. Greenwood is an 11,400-acre piedmont reservoir used for hydroelectric power production, municipal supply, and recreation. At present there is a small infestation of about 100 acres of slender naiad in one cove of this lake. Slender naiad also occurs in the upper one fourth of 1600-acre Lake Bowen in the blue ridge region of the state. Both of these upstate lakes will probably require control operations to keep infestations from expanding.

RESPONSIBILITY AND FUNDING

Aquatic plant management in South Carolina's public waters is the responsibility of the South Carolina Aquatic Plant Management Council. This Council was established by Executive Order of the Governor in 1980 and is composed of representatives of 10 State agencies, each having an interest in natural resource management. Each year the Council conducts surveys to identify aquatic plant problem areas, develops management strategies for each problem area, and allocates available public funding among problem areas for plant control operations.

Since 1981, South Carolina has participated with the Corps of Engineers, Charleston District, in a Cooperative Aquatic Plant Control Program in which the cost of control operations is shared on a 70-percent Federal and 30-percent local basis. During 1981 through 1983, the Corps provided $260,500 which was matched with $111,643 in local funds for a total expenditure of $372,143. Thse funds were used to control about 2500 acres of weed-infested public waters (Lake Marion and Goose Creek Reservoir). Other non-Federal funding during this period amounted to $230,000 expended primarily by the South Carolina Public Service Authority for management of the Santee-Cooper Lakes.

To date, funding for the plant control effort in South Carolina has been far short of the amount needed. It is currently estimated that at least $800,000 could be utilized annually for aquatic weed control in the state's public waters. It is hoped that the increase in Federal funding limit from $5 million to $10 million for Fiscal Year 1984-85 will result in an increased level of assistance for plant control in South Carolina. In addition, there are plans to appropriate $500,000 in State funds for aquatic plant research and control operations in FY 1984-85.

END

FILMED

9-84

DTIC